25990-H037-R0-00

NASA CR-
147452

PROJECT TECHNICAL REPORT
TASK ASTP-E101

VERIFICATION TEST RESULTS OF APOLLO STABILIZATION AND CONTROL SYSTEMS DURING UNDOCKED OPERATIONS

NAS9-13834 — 14 JUNE 1974

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS

(NASA-CR-147452) VERIFICATION TEST RESULTS OF APOLLO STABILIZATION AND CONTROL SYSTEMS DURING UNDOCKED OPERATIONS (TRW Systems Group) 146 p HC $6.00 CSCL 22B

N76-18216

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Prepared by
Electronic System Engineering Department
Electronic Systems Laboratory

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Prepared by
E. L. Copeland
R. L. Haken

Approved by R. L. Haken
R. L. Haken
Task Manager

Approved by W. B. Warren
W.B. Warren, Acting Manager
Electronic Systems
Engineering Department

CONTENTS

1. INTRODUCTION AND SUMMARY

This document is presented in partial fulfillment of Task JSC/TRW ASTP-E101 (see Reference 1). The results presented herein represent analysis and simulation testing of both the Skylark 1 RCS DAP and the TVC autopilot for use during the undocked portions of the Apollo/Soyuz Test Project Mission (see Reference 2). A discussion of the test procedures and the need for testing is presented in the Test Plan (see Reference 3). Autopilot testing for the docked portions was reported in Reference 4.

The RCS DAP testing was performed using the JSC/ASED Skylab Functional Simulator (SLFS) (see References 5 and 6). This simulation model is a digital computer program capable of simulating the Apollo and Skylab autopilots along with vehicle dynamics including bending and sloshing. The model is used to simulate three-axis automatic maneuvers along with pilot controlled manual maneuvers using the RCS DAP.

The TVC autopilot was tested in two parts. A classical stability analysis was performed on the vehicle considering the effects of structural bending and sloshing when under the control of the TVC autopilot (see Reference 7). The time response of the TVC autopilot was also tested using the SLFS and is reported herein.

Data for the study were taken essentially from three sources. The erasable memory constants for the guidance and control software were taken from the GSOP (Reference 2). Mass properties along with vehicle geometry and structural dynamical data were taken from References 8 and 9. The actual data used are included, in part, in Appendixes A and B.

Results of the study indicate that adequate performance stability margins can be expected for the CSM/DM configuration when under the control of the Apollo control systems tested herein.

2. DATA USED IN THE STUDY

The basic weights data used for the study were obtained from Reference 8. The data used were supplied in the English system of units. The simulation program performed the conversion to the metric system.

The bending data were taken from Enclosure 2 of Reference 12. The data used were presented in the English system of units and were converted by the simulation program for use therein.

The loads data were taken from Reference 13. The units were English and conversion was again performed in the simulation program.

The weights, bending and loads data are summarized in the appendixes. Guidance and navigation data were taken from the GSOP, (Reference 2) and those data required to initialize the program are included in the test results.

3. RCS DAP TEST RESULTS

3.1 INTRODUCTION

The RCS DAP test cases executed are concerned with attitude hold, automatic maneuvers and X-axis RCS translation. Two cases were executed using the CSM-only DAP configuration. Two additional cases were then executed using the CSM/LM ascent DAP configuration*. For roll control jets the AC quads were chosen. The loads stations investigated were the following:

<u>Station</u>

1010	Interface between command module and service module
1109.5	Interface between CSM and DM

The vehicle state is initialized to the following orbit:

Circular orbit altitude	416700.0 m
Angle from plane of the ecliptic to orbital plane	23.5 deg
Angle from orbit noon to initial R, V	0.0 deg

The following orbital torque effects are simulated:

Orbital aerodynamics

Gravity gradient torques

* These two DAP configurations were evaluated to provide comparative measurements of performance, loads and propellant consumption.

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Results for Case 1

Case 1 uses the CSM-only DAP configuration and is defined by the following three-axis maneuver, followed by an attitude hold.

- Roll angle of rotation 5 deg
- Pitch angle of rotation 7 deg
- Yaw angle of rotation 10 deg
- Deadband 0.5 deg
- Maneuver rate 2 deg/sec
- Attitude hold 80 sec

The response time history is shown in Figures 1R-1 through 1R-13. These results are summarized in Tables 1R-1 and 1R-2.

Table 1R-1 Summary of Results
RCS Case 1

Maximum Bending Moment at Station 1010		
Torsion	6.456E2	Newton Meters
Pitch	-1.533E3	Newton Meters
Yaw	2.829E3	Newton Meters
Maximum Bending Moment at Station 1109.5		
Torsion	1.349E3	Newton Meters
Pitch	-7.189E2	Newton Meters
Yaw	7.580E2	Newton Meters
Maximum Angular Rates		
Roll	.84 Deg/Sec	
Pitch	.83 Deg/Sec	
Yaw	1.56 Deg/Sec	

The objective of this run was to demonstrate the automatic maneuver capability of the CSM-alone DAP in the performance of an automatic three-axis maneuver and to hold an inertial attitude following the maneuver. The maneuver rate was 2 deg/sec and the attitude deadband for both the maneuver and attitude hold was 0.5 deg.

The DAP satisfactorily performed the automatic maneuver to the specified attitude and satisfactorily maintained the inertial attitude within the specified deadband. The total fuel consumed during this 100 second simulation was 4.095 pounds (1.86 Kg). A summary of the RCS jet activity is contained in Table 1R-2.

The roll, pitch and yaw phase-planes are presented in Figures 1R-1 through 1R-3 respectively. At a simulation time of 2 seconds the automatic maneuver sequence was initialized. The requested spacecraft rates were 0.83, 0.91 and 1.57 deg/sec about the roll, pitch and yaw axes. The DAP computed the rate bias <u>WBODY</u> and attitude bias <u>BIAS</u> to initiate the maneuver. This placed the phase-plane state outside the coast zone and the DAP responded with the appropriate firings to reduce the errors and establish the desired rates. The initial firings were computed to reduce the rate error to the negative rate ledge (-WL). The subsequent firings were in accordance with the phase-plane logic and reduced the rate and attitude errors to acceptable values.

At the simulation time of 8.7 seconds, the computed maneuver time had elapsed, and the automatic maneuver was terminated. The biases <u>WBODY</u> and <u>BIAS</u> were removed which once again placed the phase-plane states outside the coast zones. Appropriate jets were turned on to damp the maneuver rates. Minimum impulse limit cycles were established in all axes within approximately eleven seconds.

Time histories of the actual spacecraft rates are shown in Figure 1R-4 through 1R-6 and the corresponding DAP estimated rates are shown in Figure 1R-7 through 1R-9. The estimated rates closely resembled the actual rates and showed no adverse effects of body bending.

The only axis in which body bending is at all noticeable is the roll axis shown in Figure 1R-4. The amplitudes of the induced oscillations were small and were imperceptible in the roll axis filtered rate and thus had little or no effect on the DAP performance.

The time histories of the pitch and yaw bending moments at the CM/SM and the CM/DM interfaces are shown in Figures 1R-10 through 1R-13. A summary of the peak bending moments for all three axes is contained in Table 1R-1. In all cases these values are within the design limits and pose no problems.

TABLE 1R-2

RCS JET ACTIVITY AND FUEL CONSUMPTION SUMMARY FROM TZERO TO TIME = 99.99900

JET	NFIRE	TRCON (SEC)	FUEL (KG)	FUEL (LB)
1	4	.79854	.14037	.30946
2	11	.88873	.16602	.36602
3	4	.79854	.14037	.30946
4	11	.88873	.16602	.36602
5	9	1.54169	.27291	.60167
6	11	1.50175	.26918	.59345
7	9	1.54169	.27291	.60167
8	11	1.50175	.26918	.59345
13	4	.19694	.03913	.08626
14	5	.19997	.04114	.09069
15	4	.19694	.03913	.08626
16	5	.19997	.04114	.09069
TOTAL ALL JETS	88	10.25525	1.85750	4.09510

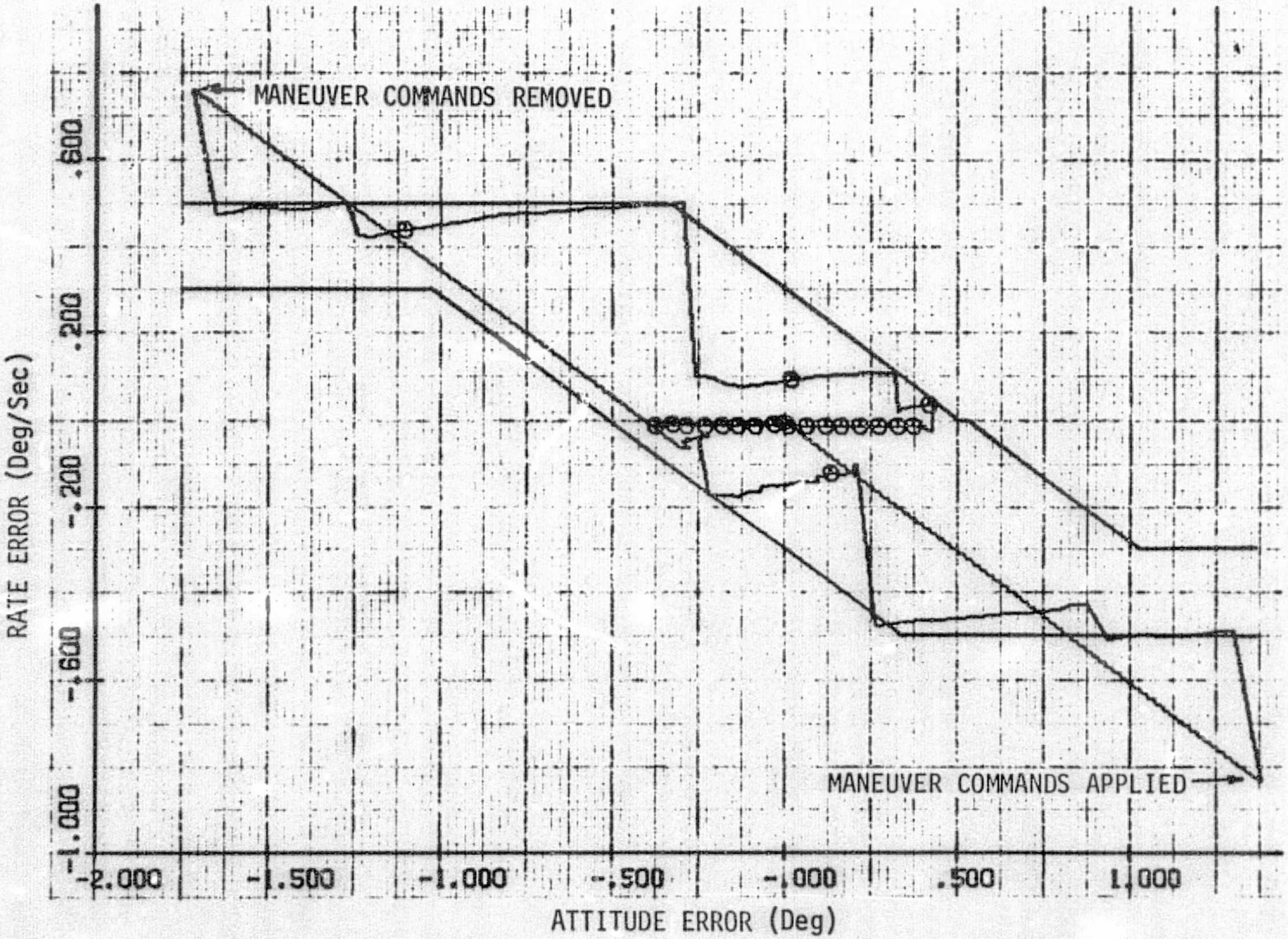


Figure 1R-1 Roll Axis Phase Plane
Case RCS-1

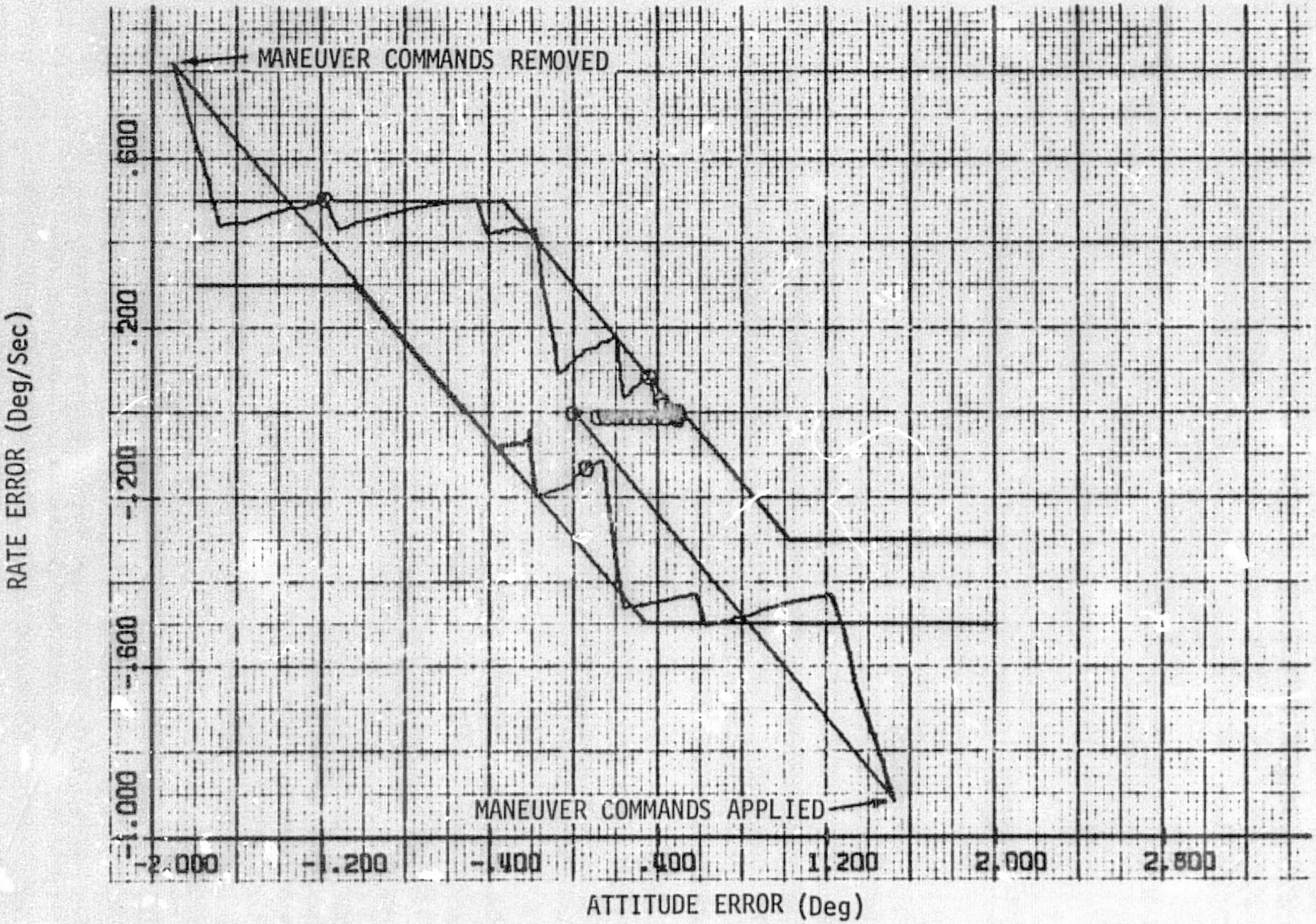


Figure 1R-2 Pitch Axis Phase Plane
Case RCS-1

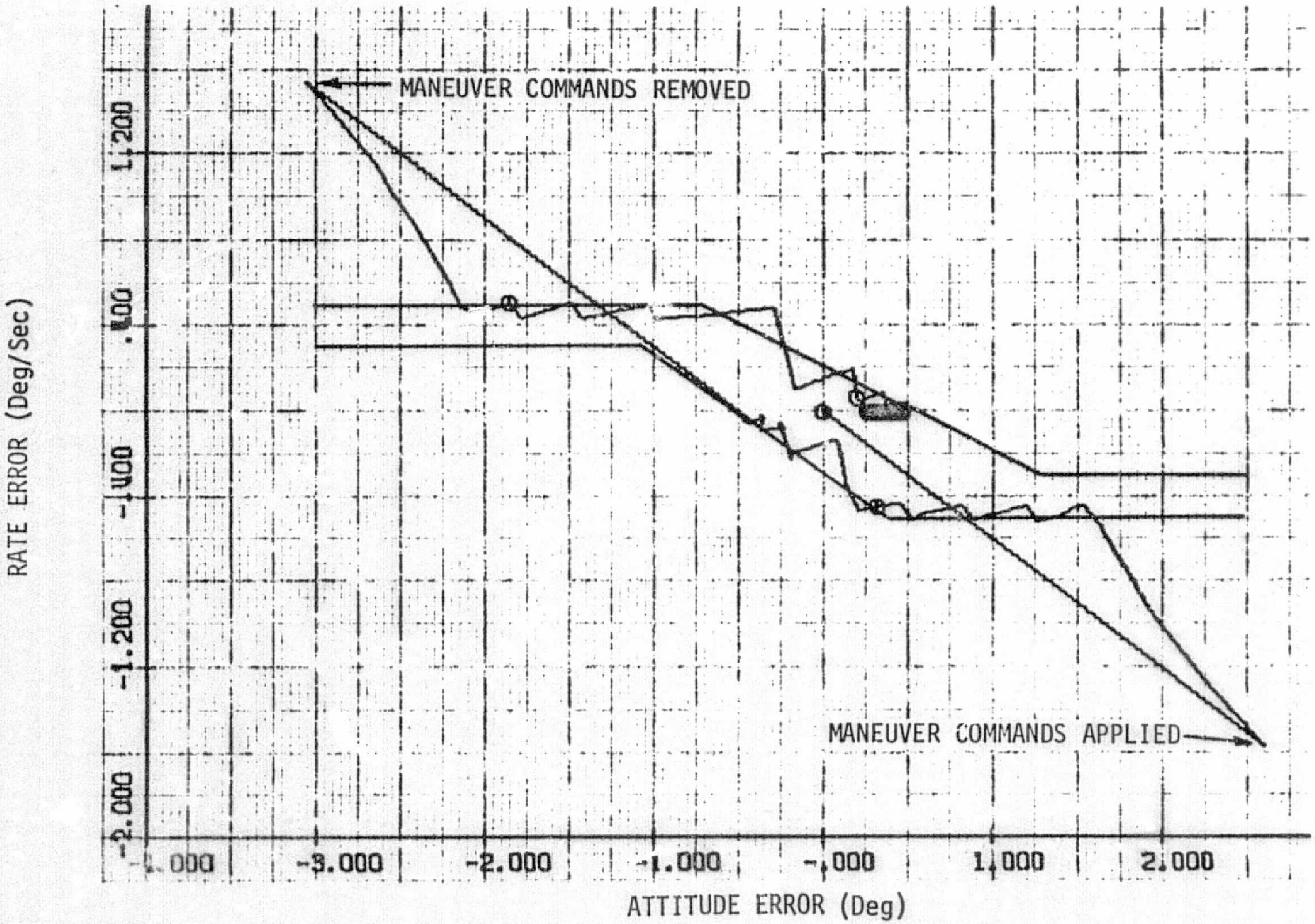


Figure 1R-3 Yaw Axis Phase Plane
Case RCS-1

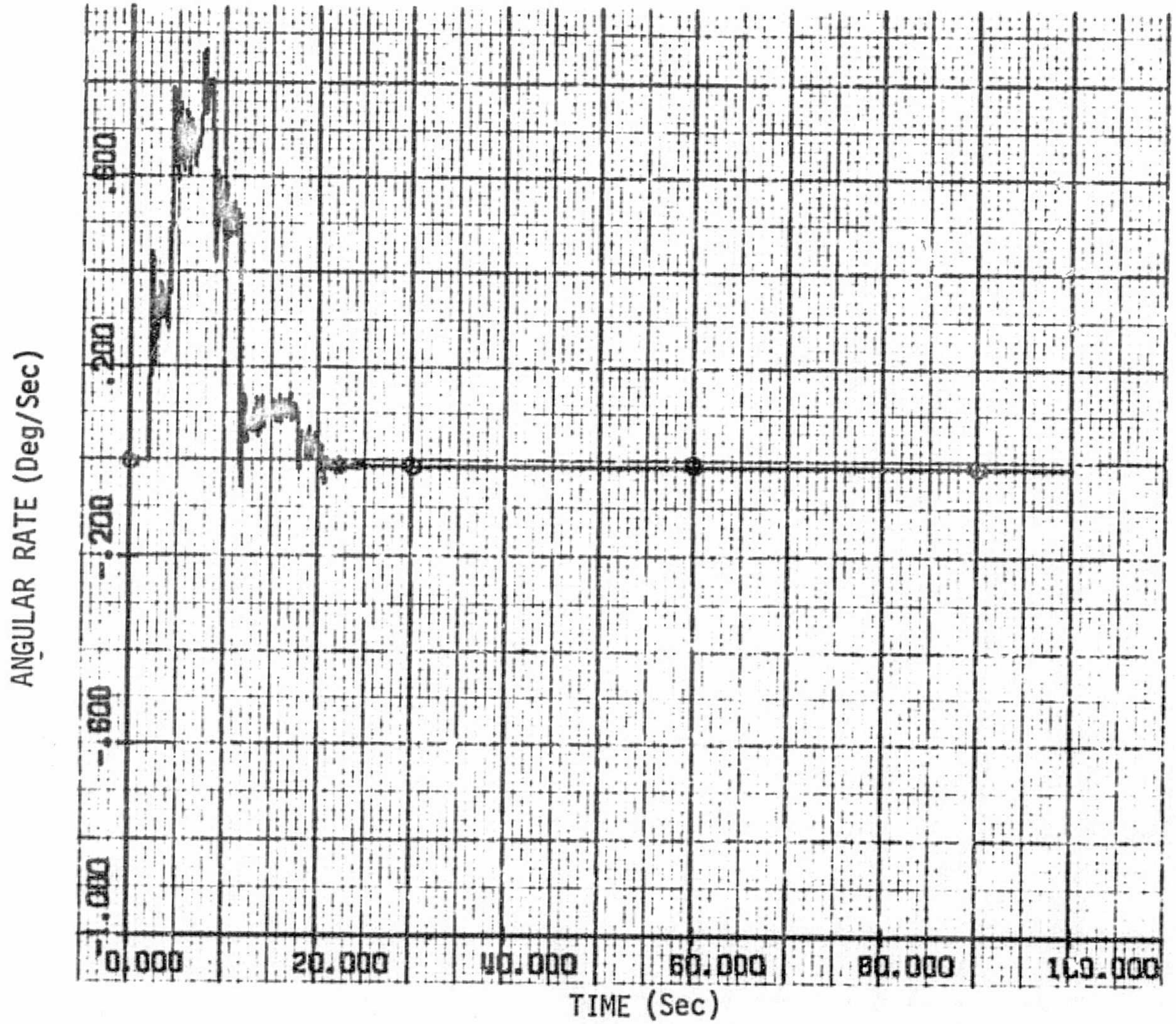


Figure 1R-4 X-Axis Angular Rate Versus Time
Case RCS-1

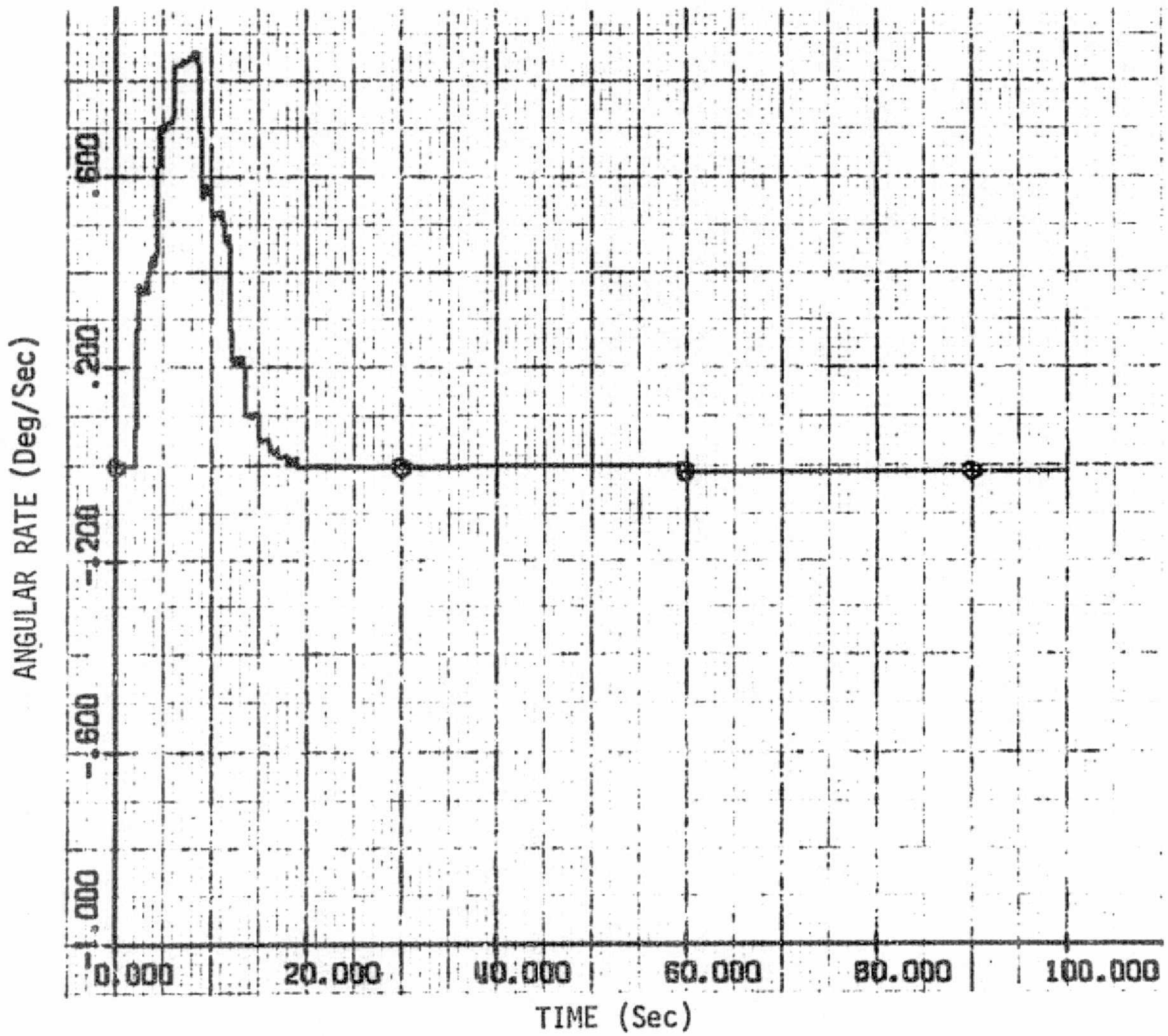


Figure 1R-5   Y-Axis Angular Rate Versus Time
Case RCS-1

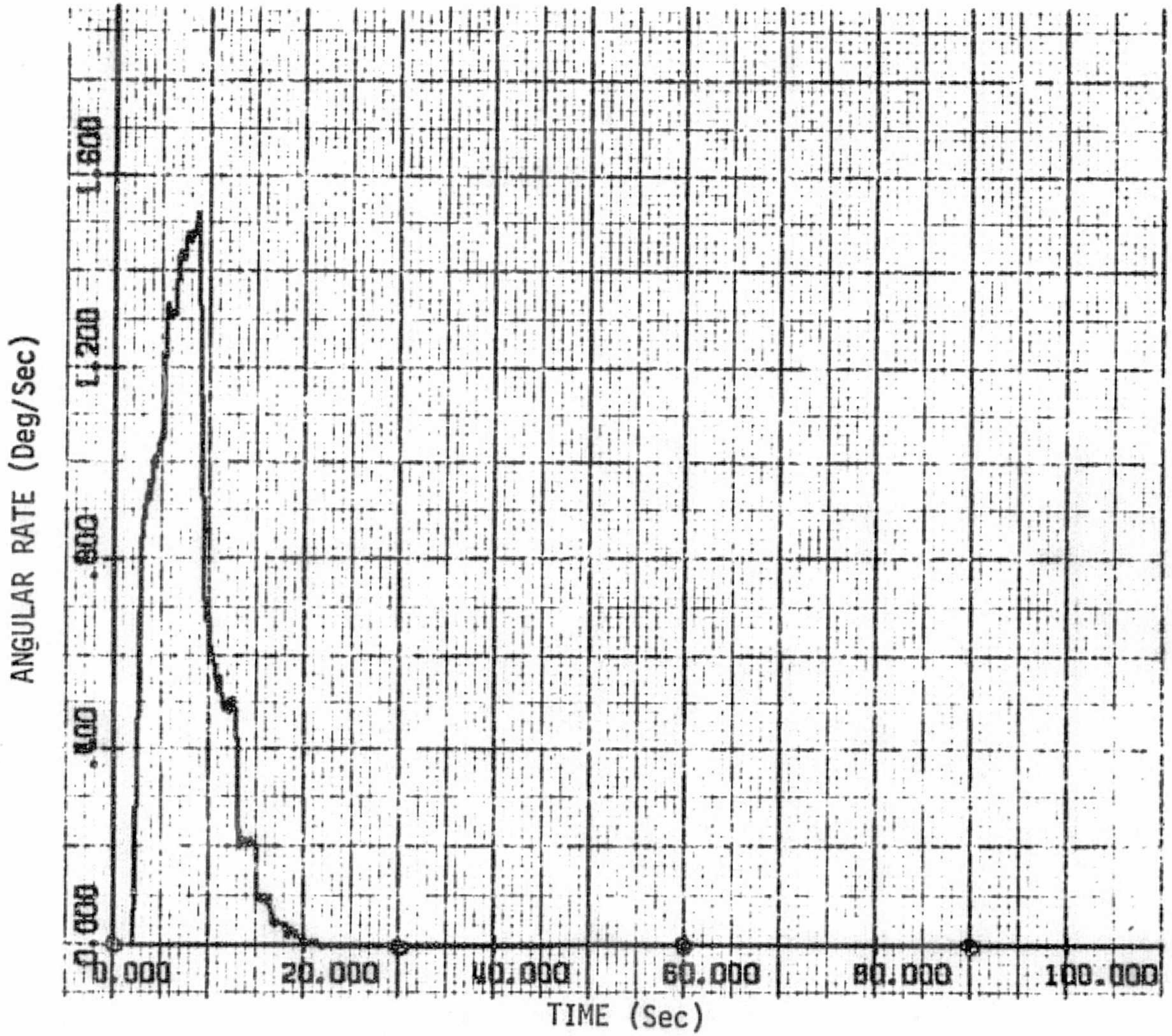


Figure 1R-6 Z-Axis Angular Rate Versus Time
Case RCS-1

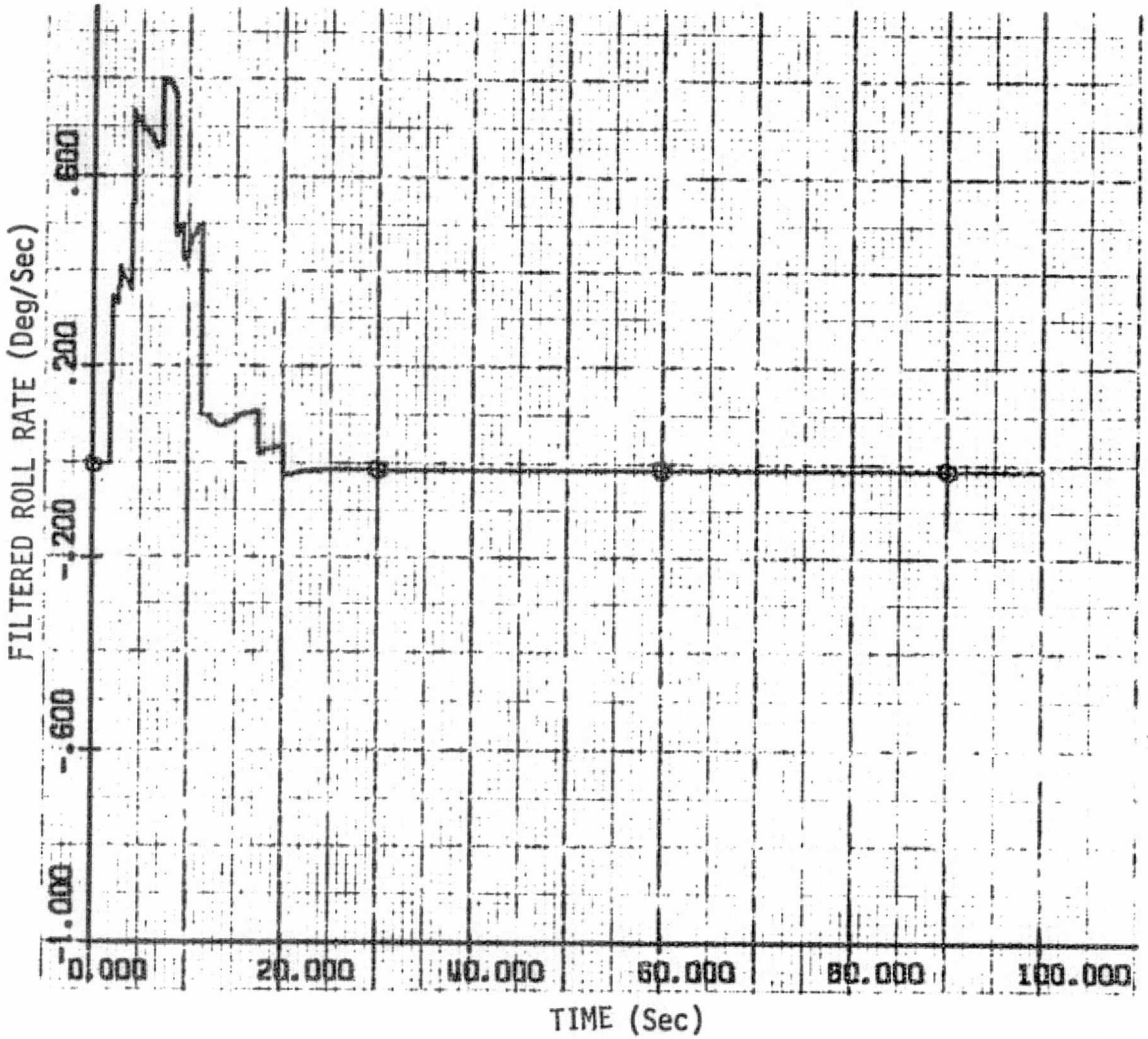


Figure 1R-7 Filtered Roll Rate Versus Time
Case RCS-1

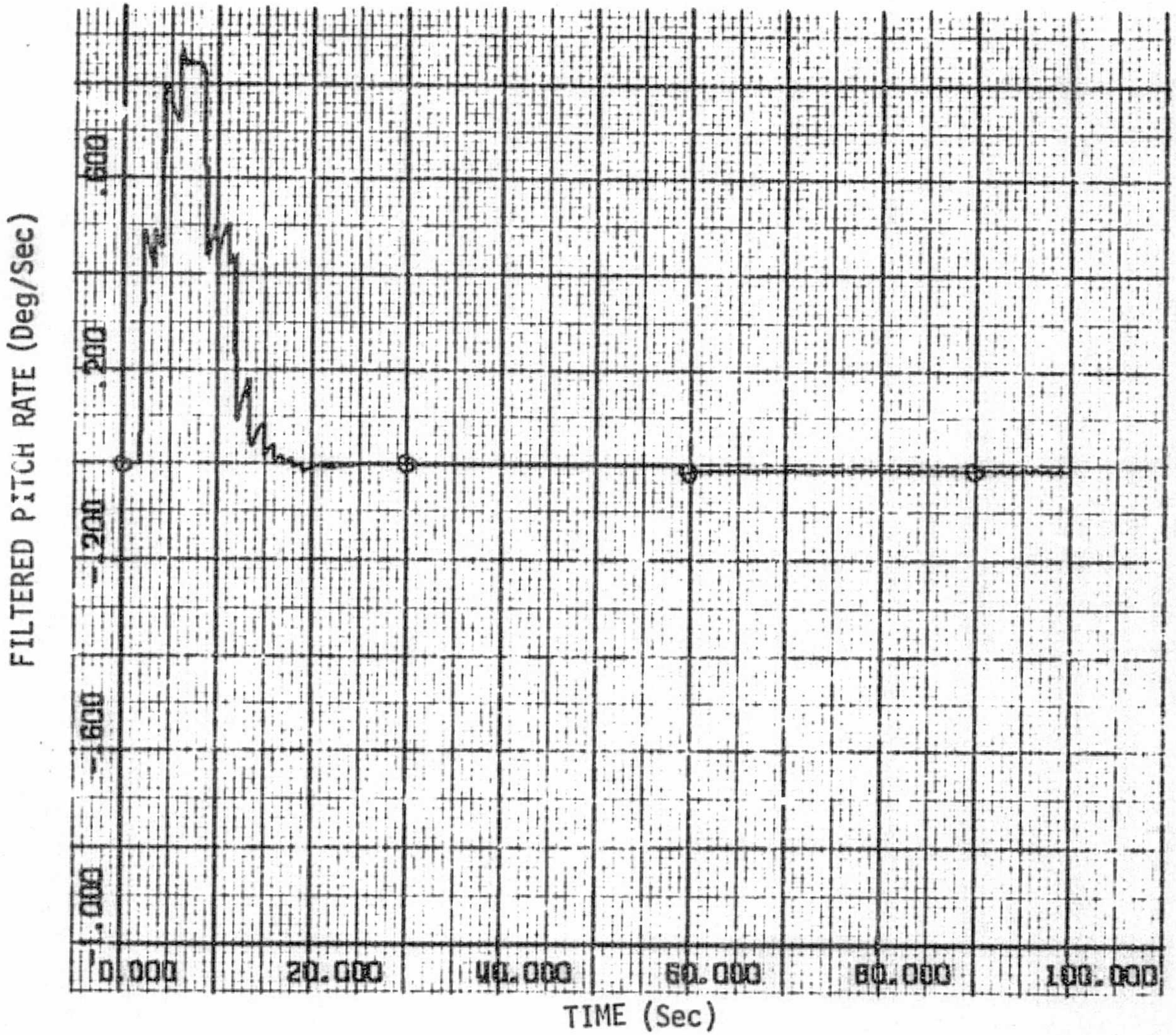
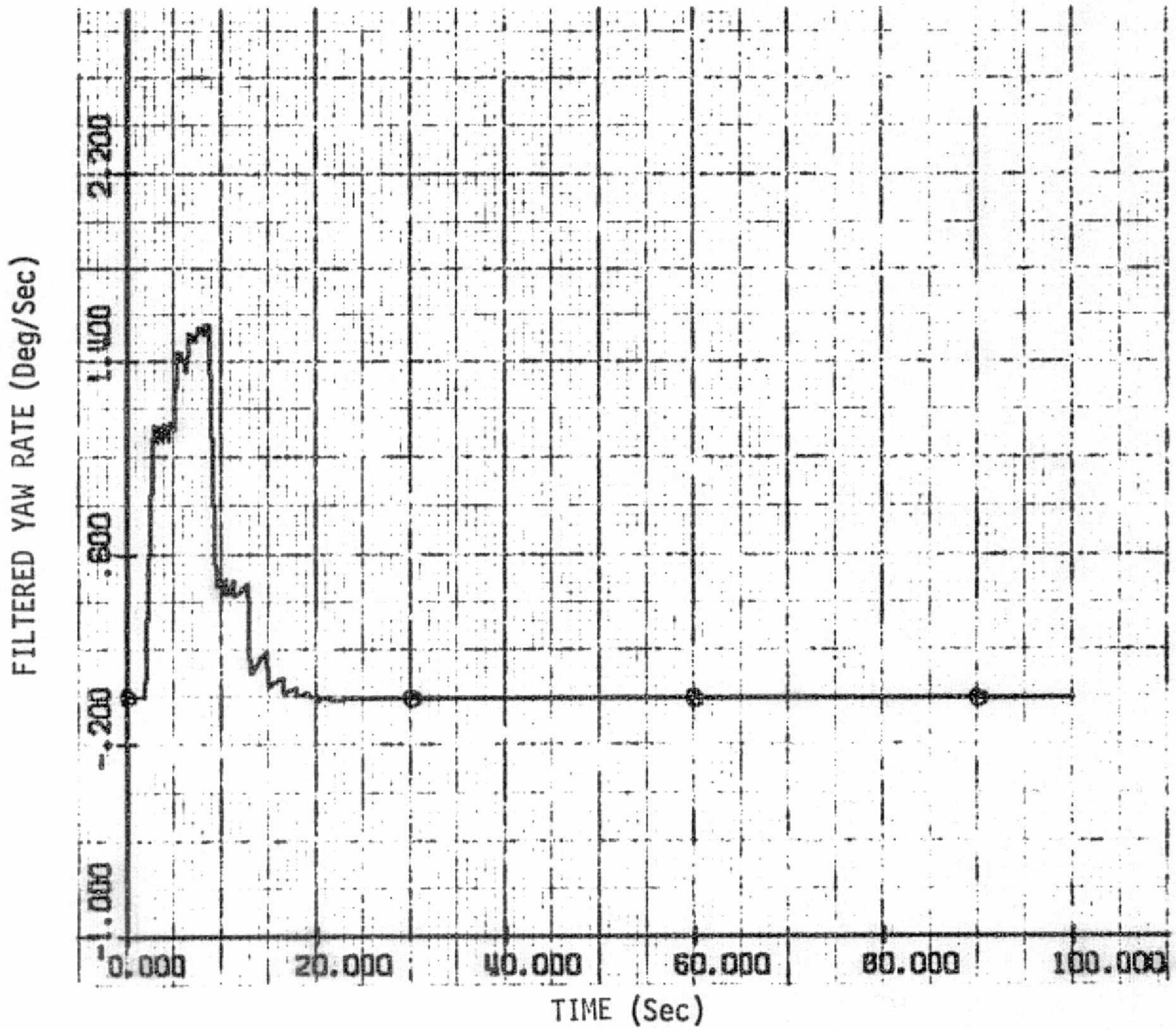


Figure 1R-8 Filtered Pitch Rate Versus Time
Case RCS-1



Fiugre 1R-9 Filtered Yaw Rate Versus Time
Case RCS-1

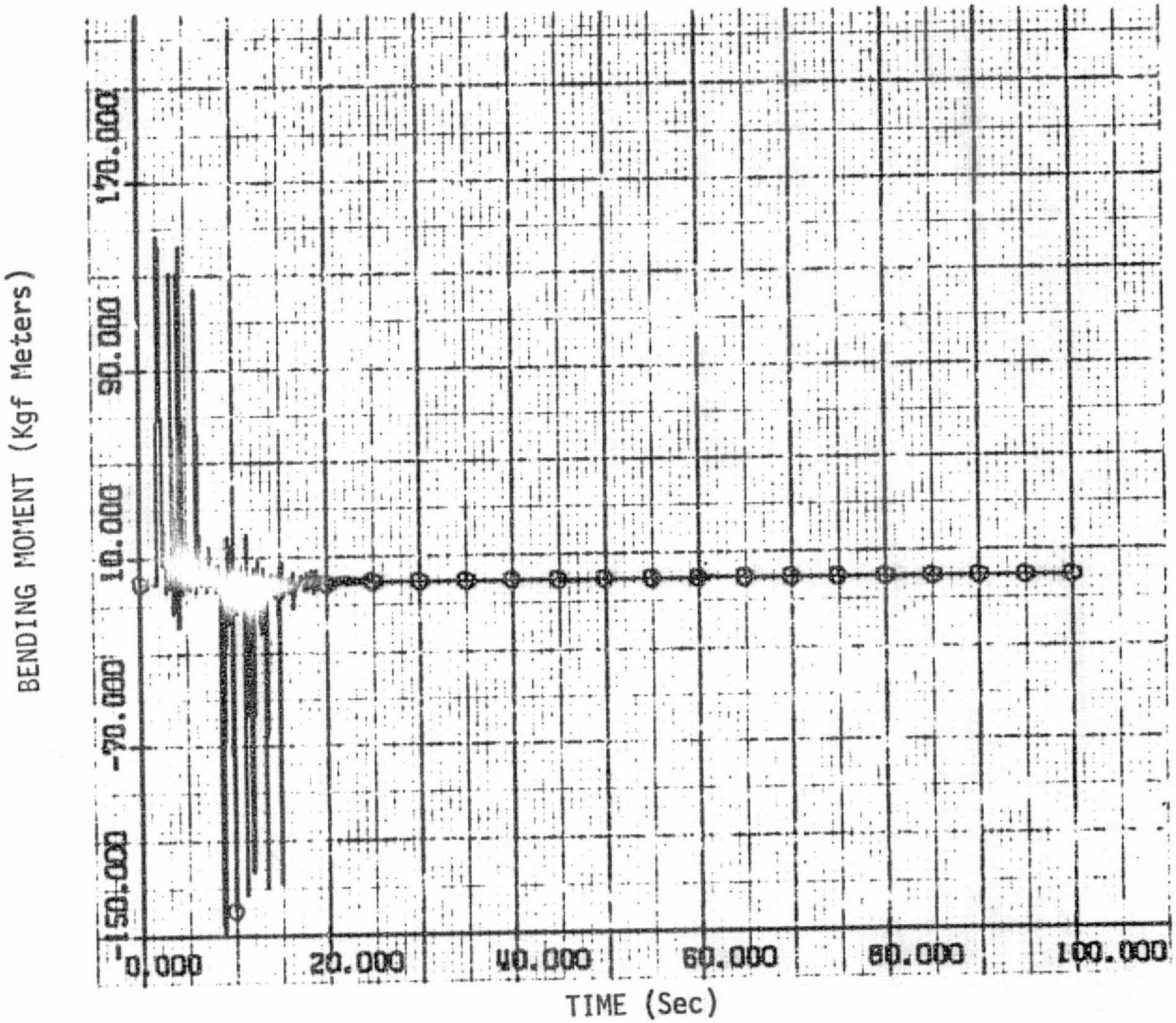


Figure 1R-10 Pitch Bending Moment at Station 1010 Versus Time
Case RCS-1

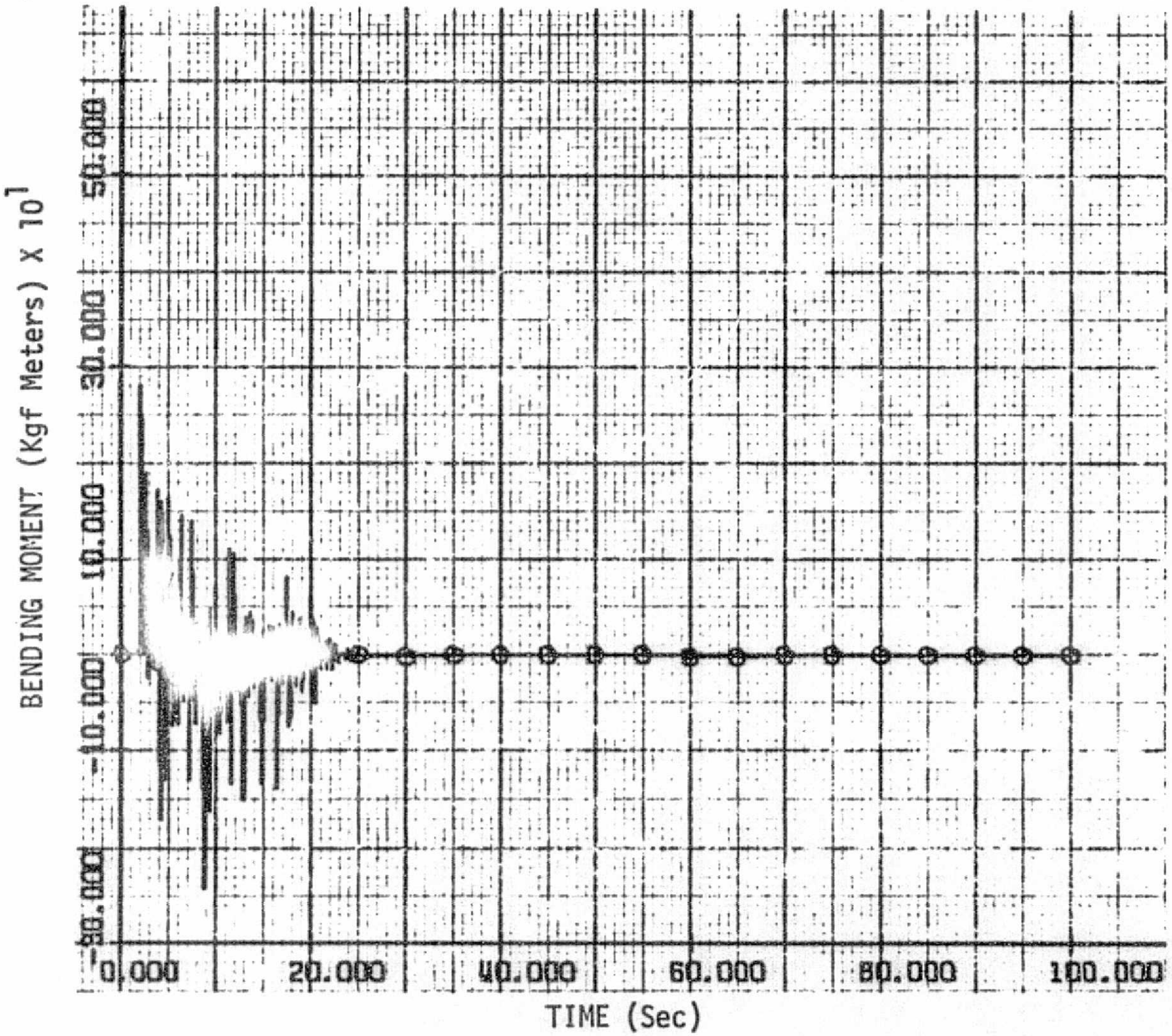


Figure 1R-11 Yaw Bending Moment at Station 1010 Versus Time
Case RCS-1

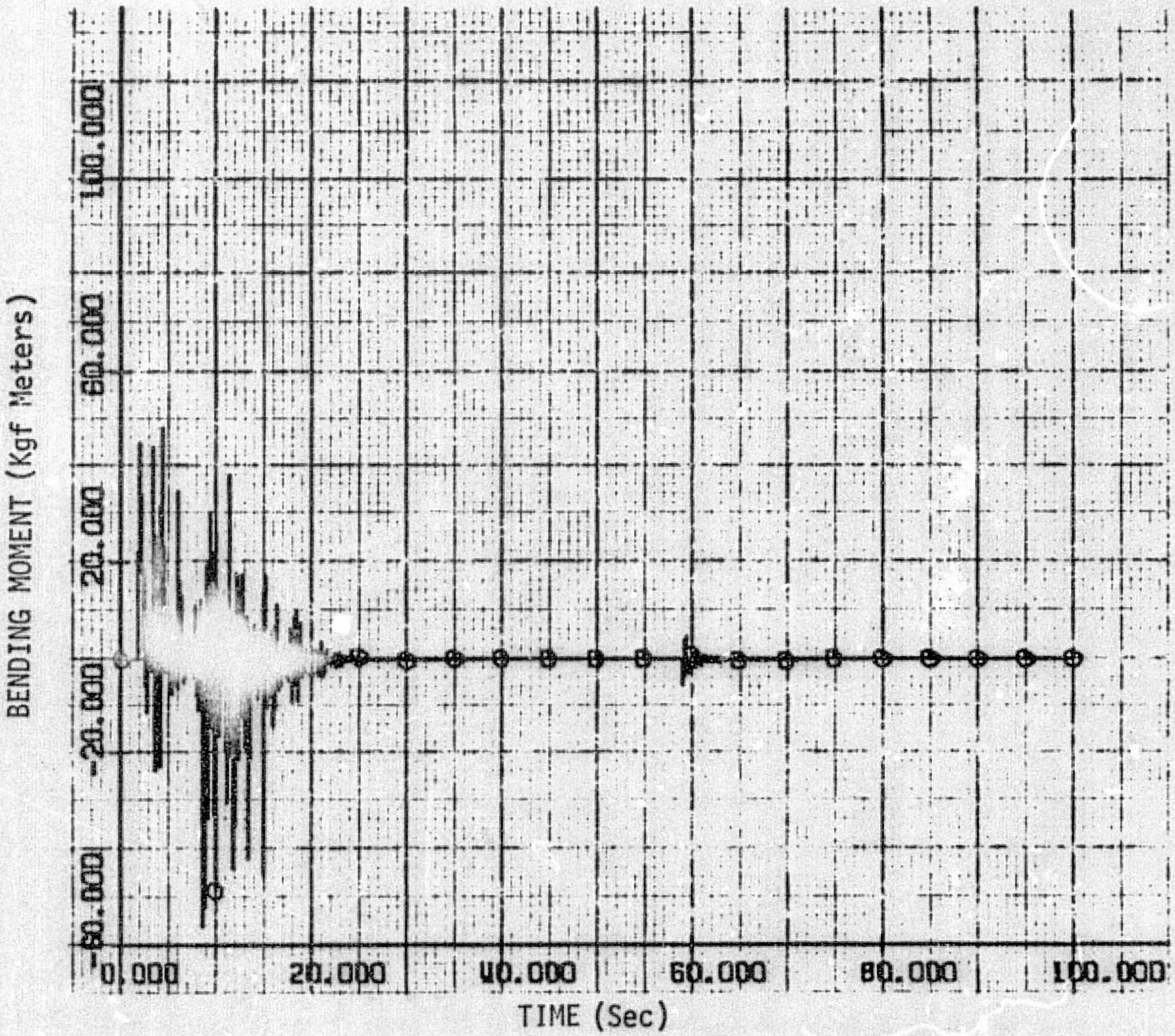


Figure 1R-12 Pitch Bending Moment at Station 1109.5 Versus Time
Case RCS-1

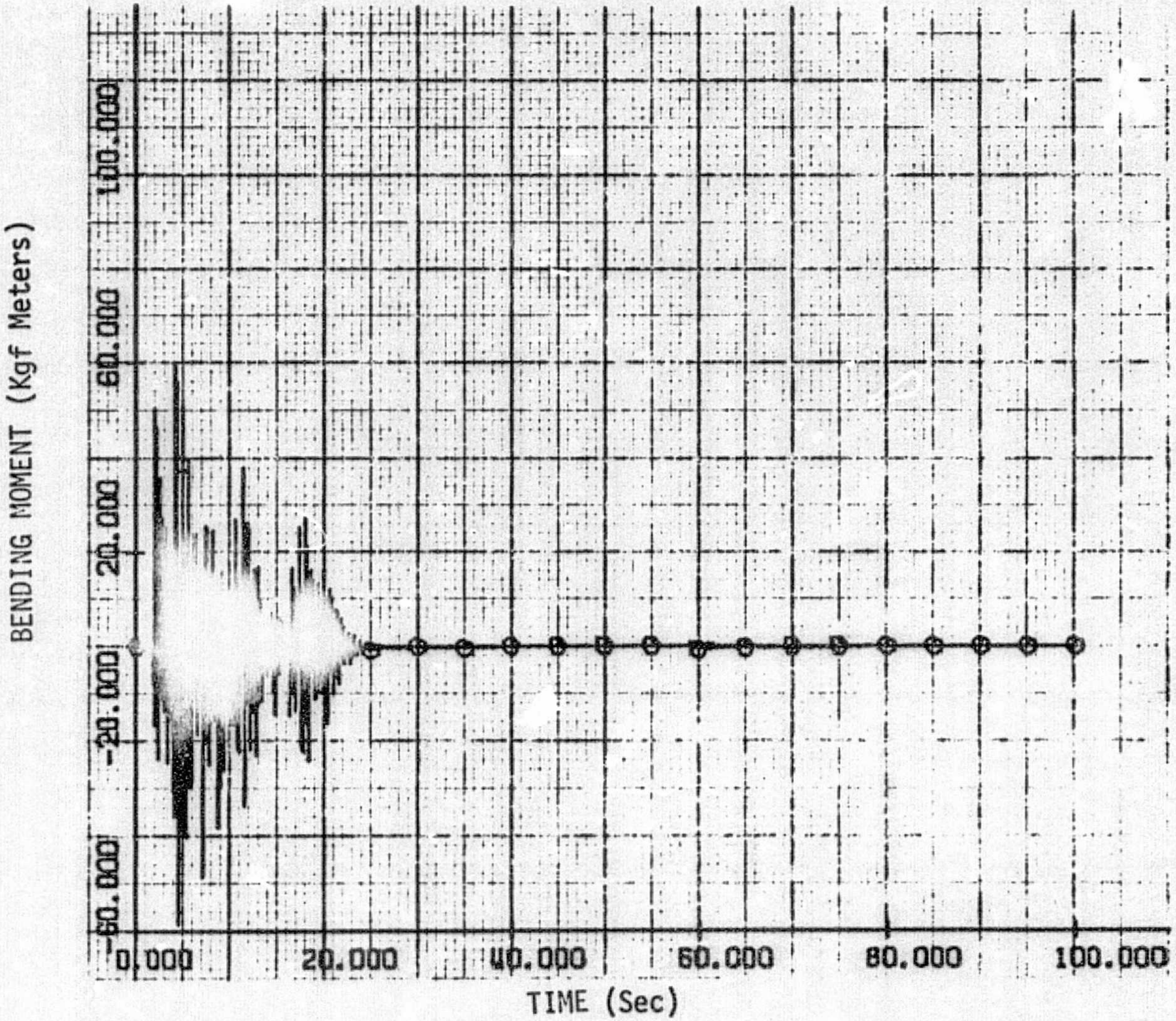


Figure 1R-13 Yaw Bending Moment at Station 1109.5 Versus Time
Case RCS-1

Results for Case 2

Case 2 is defined by the following maneuver:

- Four jet X-translation THC out of detent — 20 sec
- Positive pitch rotation RHC out of detent — 5 sec
- Attitude hold — 60 sec
- Deadband — 0.5 deg

Simulated response time histories are presented in Figures 2R-1 through 2R-9. Tabulated summaries are shown in Tables 2R-1 and 2R-2.

Table 2R-1 Summary of Results
RCS Case 2

Maximum Bending Moment at Station 1010		
Torsion	1.637E2	Newton Meters
Pitch	1.332E3	Newton Meters
Yaw	-1.166E3	Newton Meters
Maximum Bending Moment at Station 1109.5		
Torsion	-1.262E3	Newton Meters
Pitch	5.660E2	Newton Meters
Yaw	-2.070E2	Newton Meters
Maximum Angular Rate Magnitudes		
Roll	.15	Deg/Sec
Pitch	2.1	Deg/Sec
Yaw	.11	Deg/Sec

The objective of this run was to demonstrate the RCS DAP capability to perform a manual + X translation with automatic attitude hold and to perform a positive pitch rotation with the rotational hand controller. The pitch rate was 2 deg/sec and the attitude deadband was 0.5 deg throughout the run.

The DAP responded correctly to the THC and RHC commands and satisfactorily maintained attitude control during the period of manual commands. The total fuel consumed during this 100 second simulation was 32.2 pounds (14.6 kg). A summary of the RCS jet activity is contained in Table 2R-2.

The simulation was initialized with zero attitude and rate errors in an attitude hold mode. At a simulation time of 10 seconds the simulated astronaut requested a + X translation via the THC. The requested maneuver was a four jet X-axis translation for a duration of 20 seconds. Jets 1, 2, 5 and 6 were turned on to provide the desired translation. Throughout the burn, Jets 2 and 5 toggled on and off to provide attitude control because of the center-of-gravity offset. Jet number 5 was on for 96 percent of the time and Jet 2 was on for 86.3 percent of the time. The total fuel used for the 20 seconds of translation was 13 kg.

At a simulation time of 35 seconds the RHC was deflected and a positive pitch maneuver was requested. The desired pitch rate was 2 deg/sec and the duration of the command was 5 seconds. Figures 2 R-4 and 2 R-5 present time histories of the actual pitch axis angular rate and the estimated pitch rate. As can be observed the proper rate was obtained and the response was consistent with the DAP logic. After the RHC was returned to detent the DAP damped the rotational rates and established a minimum impulse limit cycle. Approximately 1.5 kg of propellant was used for this maneuver.

The time histories of the pitch and yaw bending moments at the CM/SM and the CM/DM interfaces are shown in Figures 2R-6 through 2R-9. A summary of the peak bending moments for all three axes is contained in Table 2R-2. In all cases these values are within the design limits and pose no problems.

TABLE 2R-2

RCS JET ACTIVITY AND FUEL CONSUMPTION SUMMARY FROM TZERO TO TIME = 99.99900

JET	NFIRE	TRCON (SEC)	FUEL (KG)	FUEL (LB)
1	21	22.13663	3.75665	8.28199
2	101	19.39319	3.41472	7.52817
3	20	2.13951	.38998	.85976
4	17	2.12576	.38318	.84476
5	17	19.21102	3.25833	7.18339
6	3	20.01937	3.37341	7.43709
8	2	.02225	.00674	.01485
13	2	.02775	.00766	.01690
14	2	.02225	.00674	.01485
15	2	.02775	.00766	.01690
16	2	.02225	.00674	.01485
TOTAL ALL JETS	189	85.14772	14.61180	32.21350

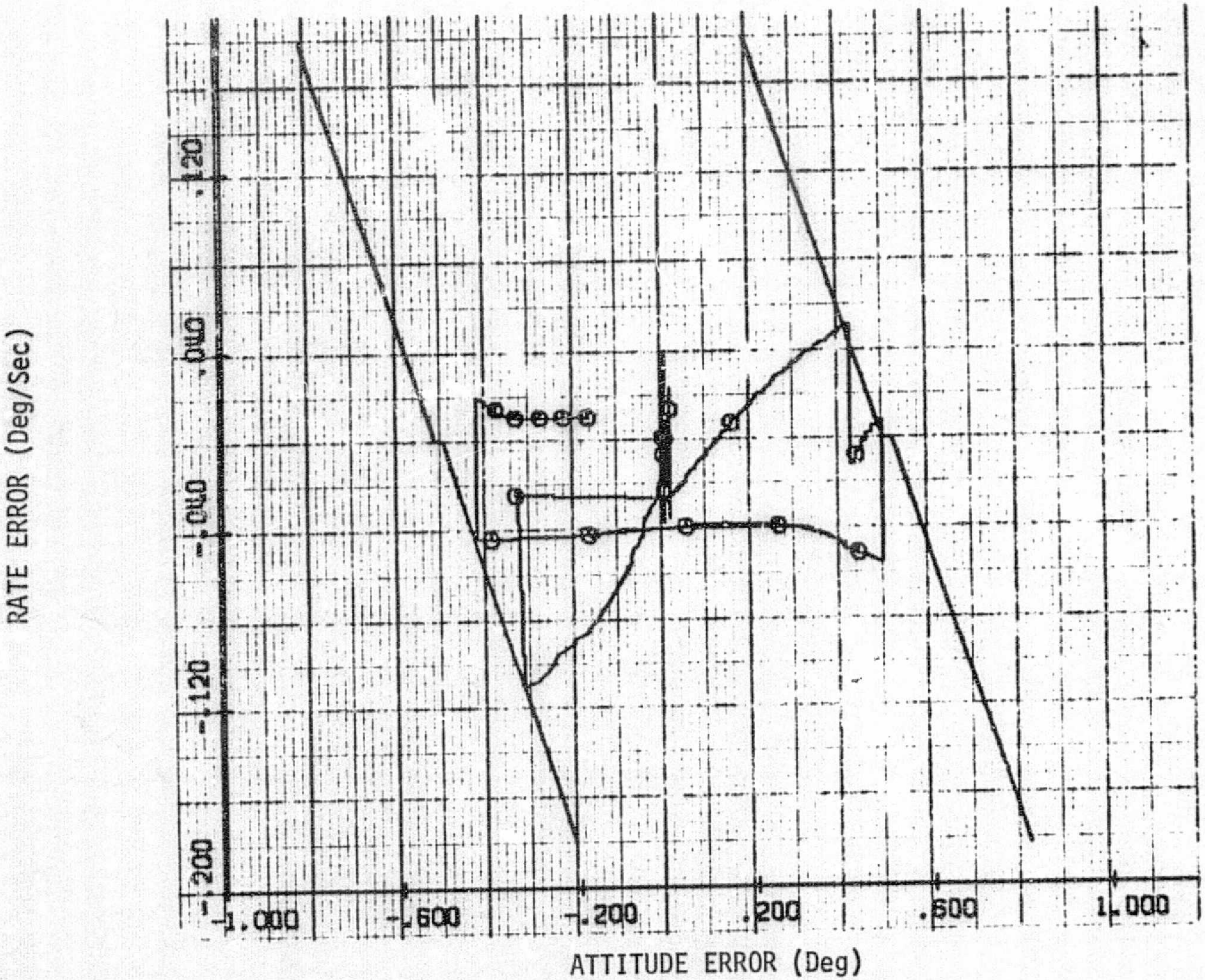


Figure 2R-1 Roll Axis Phase Plane
Case RCS-2

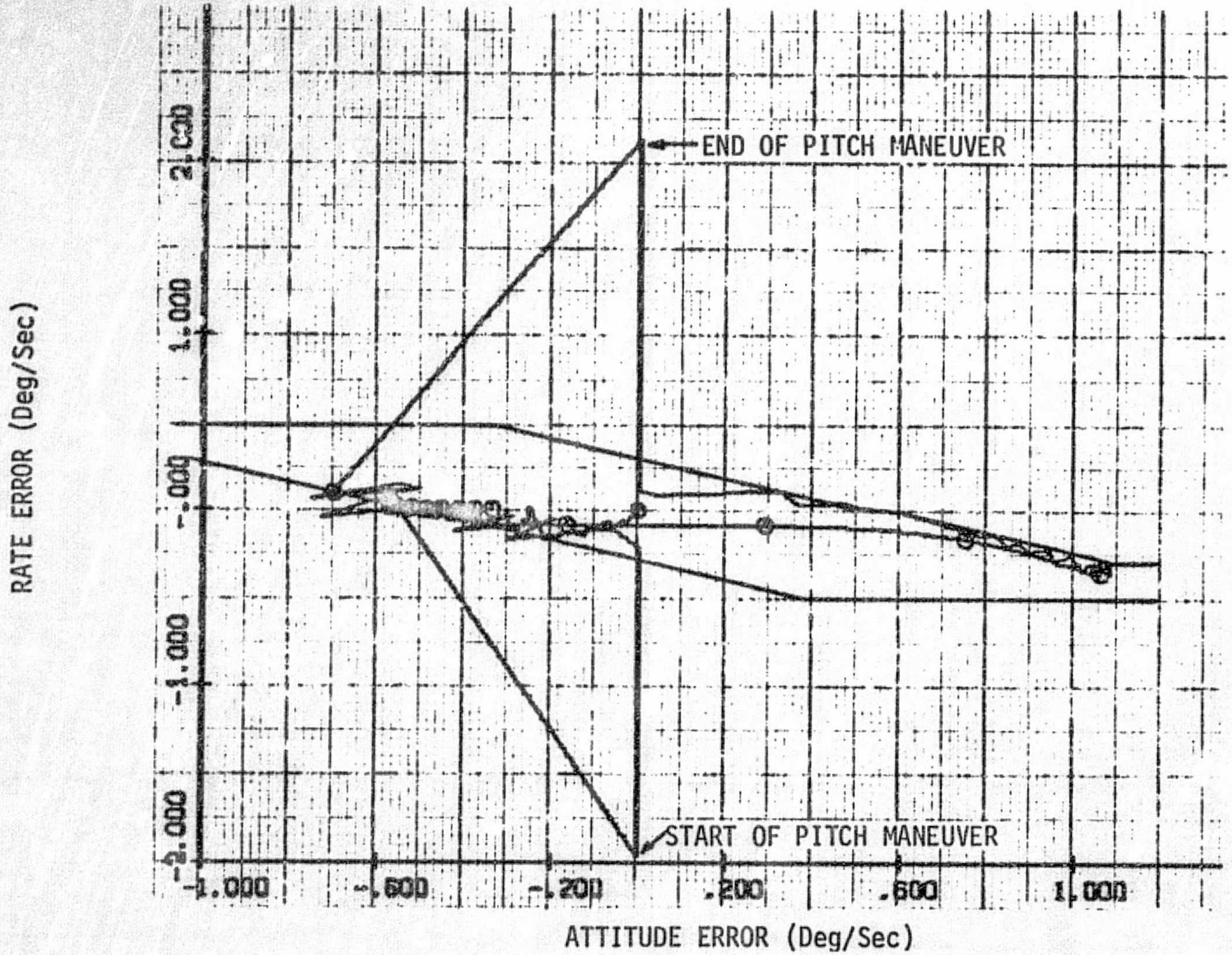


Figure 2R-2 Pitch Axis Phase Plane
Case RCS-2

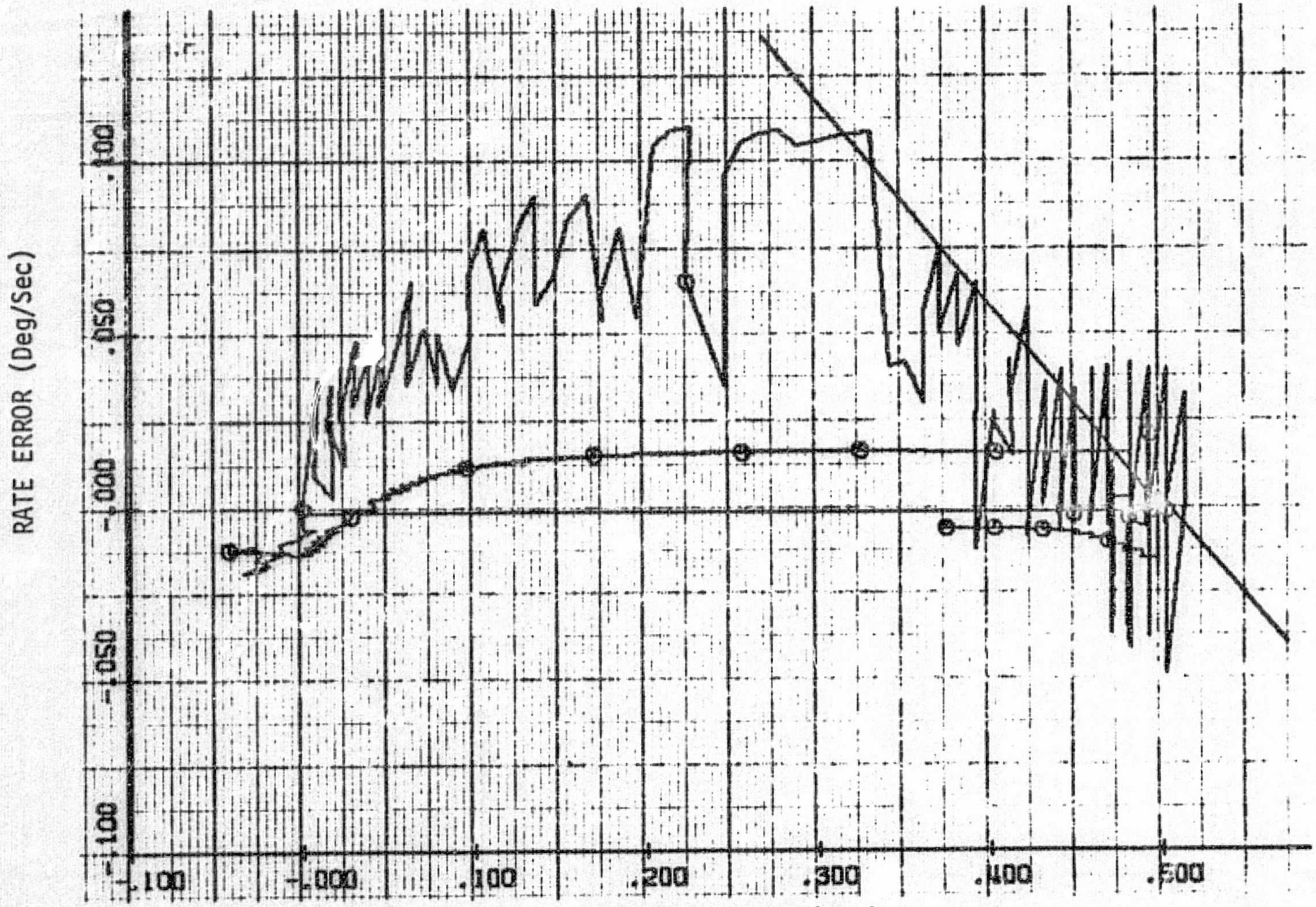


Figure 2R-3 Yaw Axis Phase Plane
Case RCS-2

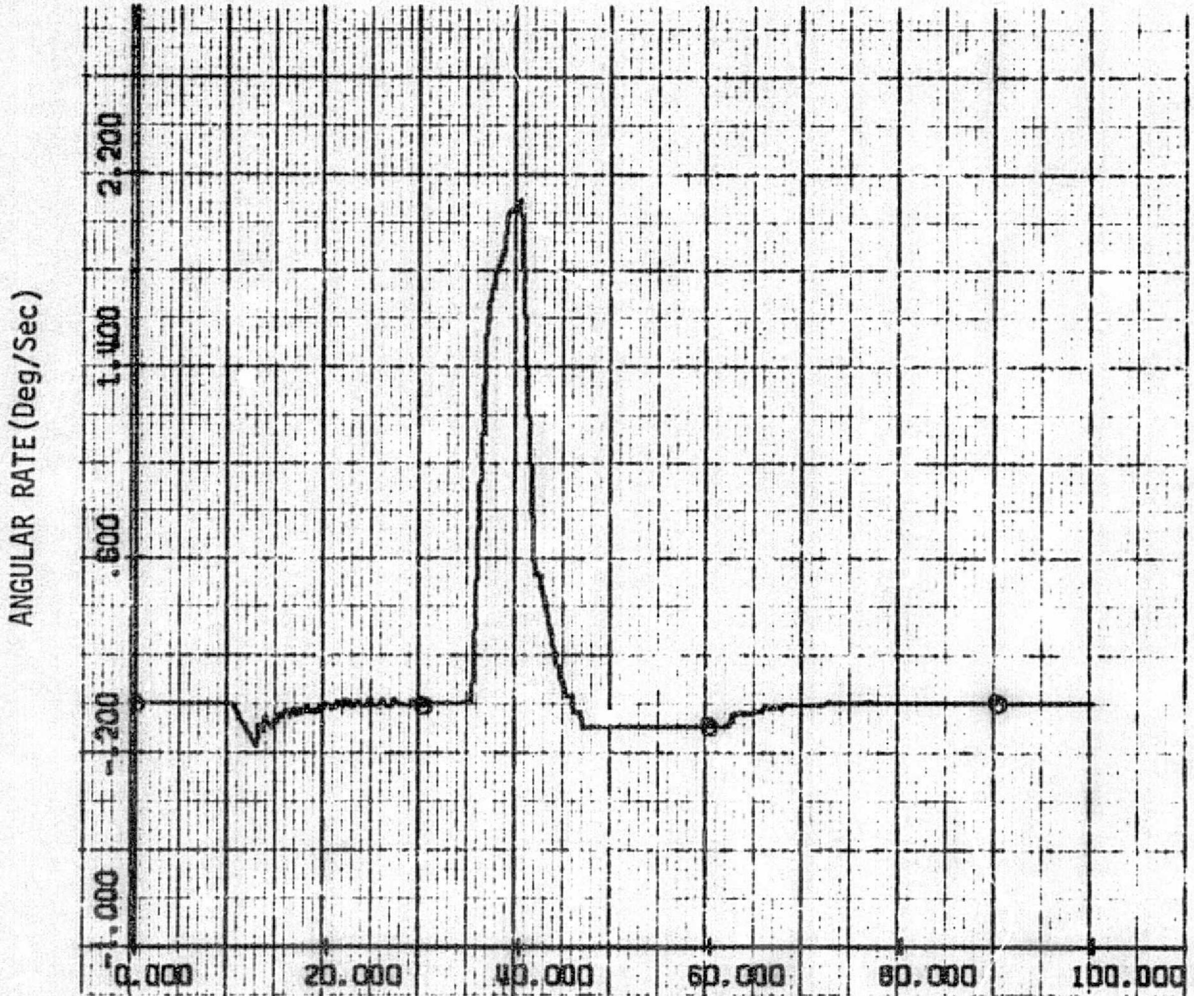


Figure 2R-4 Y-Axis Angular Rate Versus Time
Case RCS-2

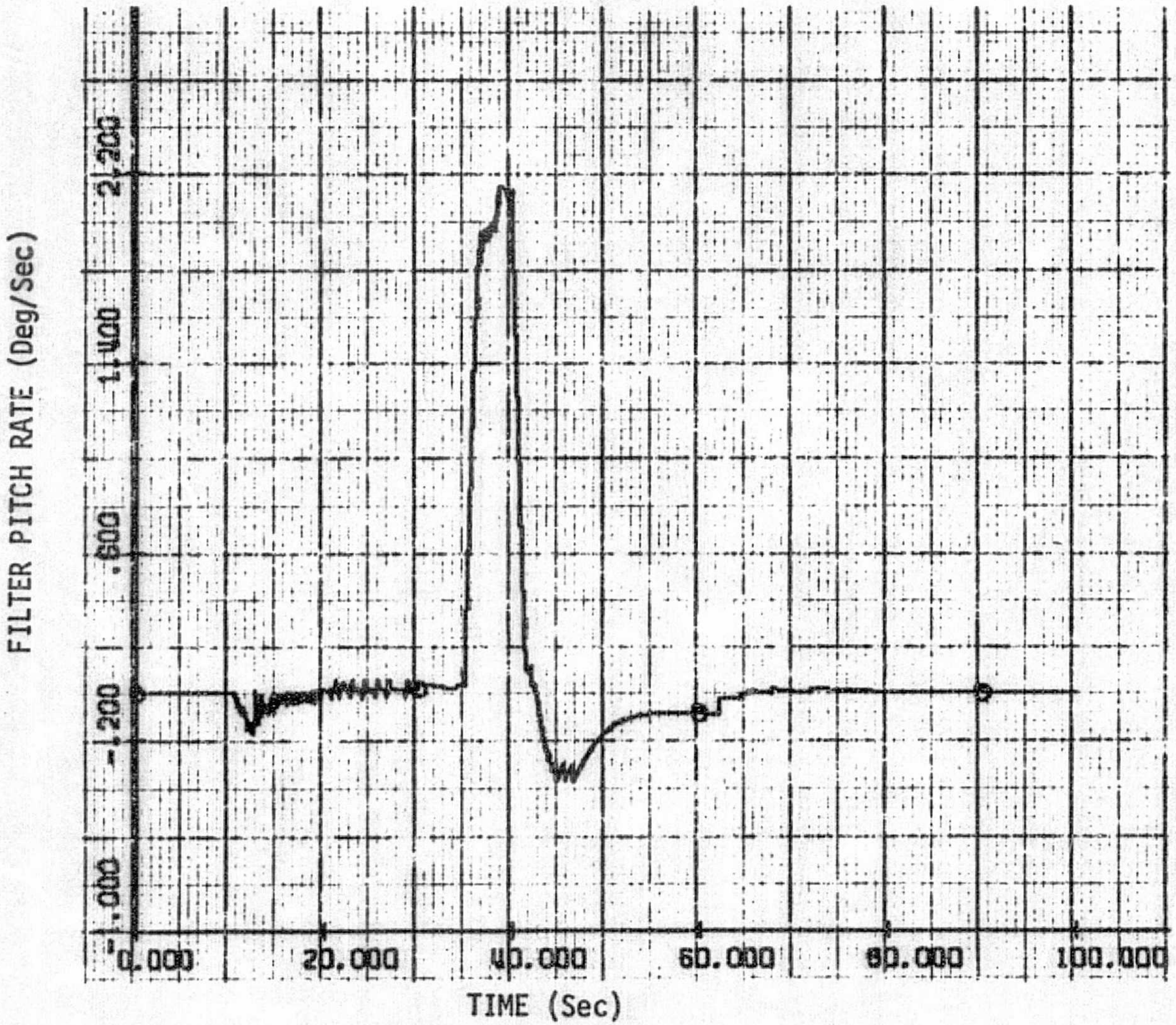


Figure 2R-5 Filtered Pitch Rate Versus Time
Case RCS-2

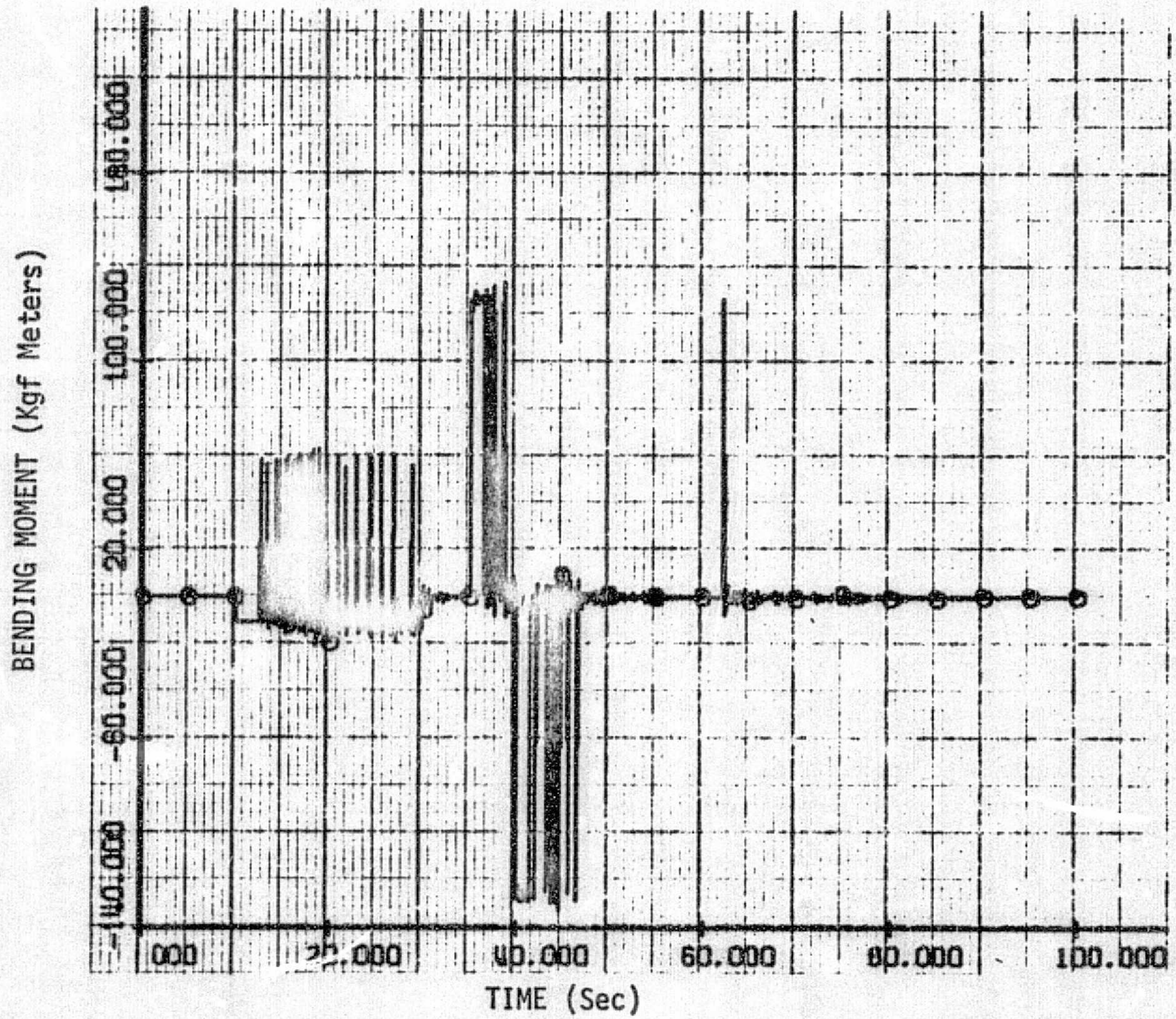


Figure 2R-6 Pitch Bending Moment at Station 1010 Versus Time
Case RCS-2

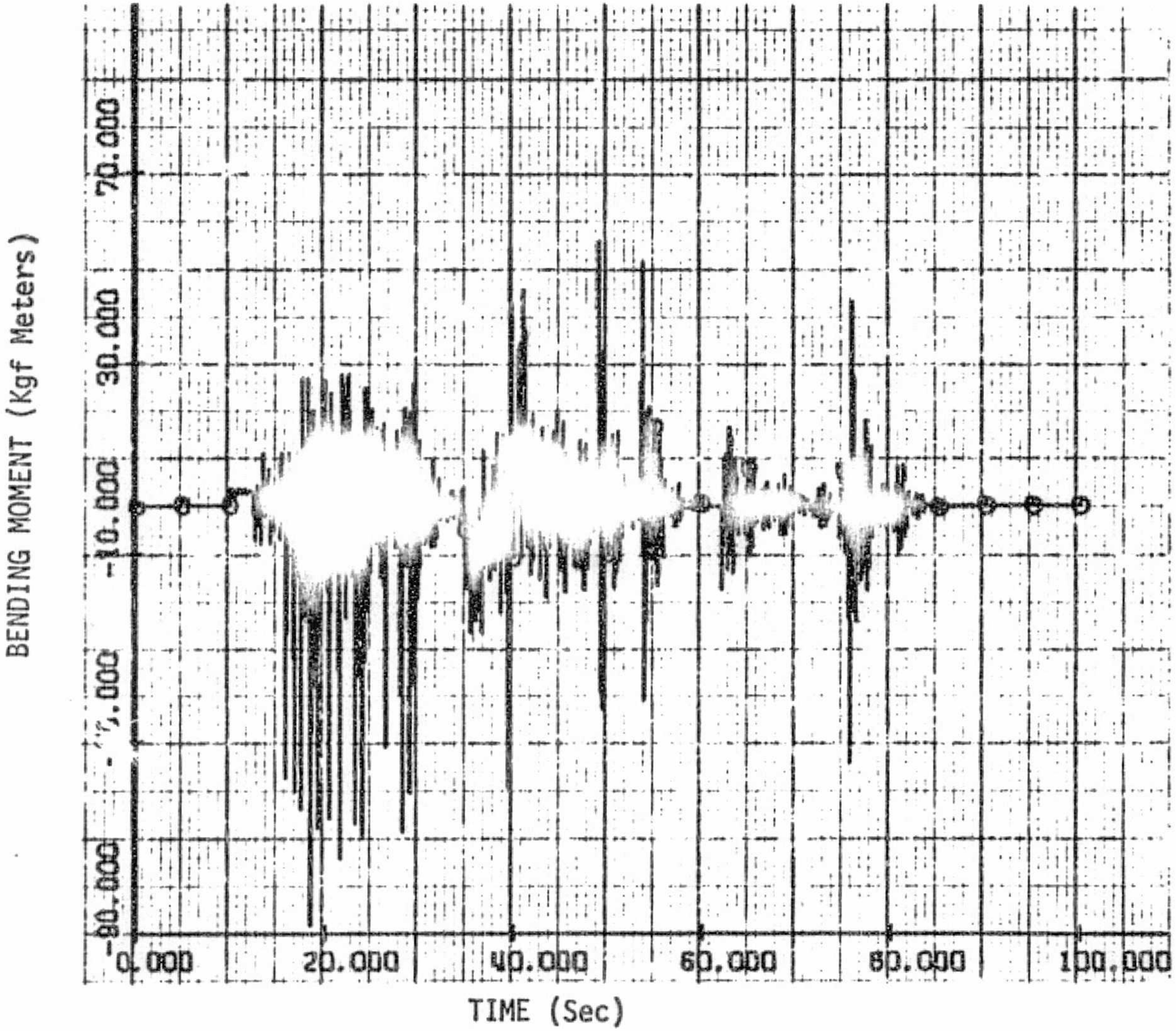


Figure 2R-7 Yaw Bending Moment at Station 1010 Versus Time
Case RCS-2

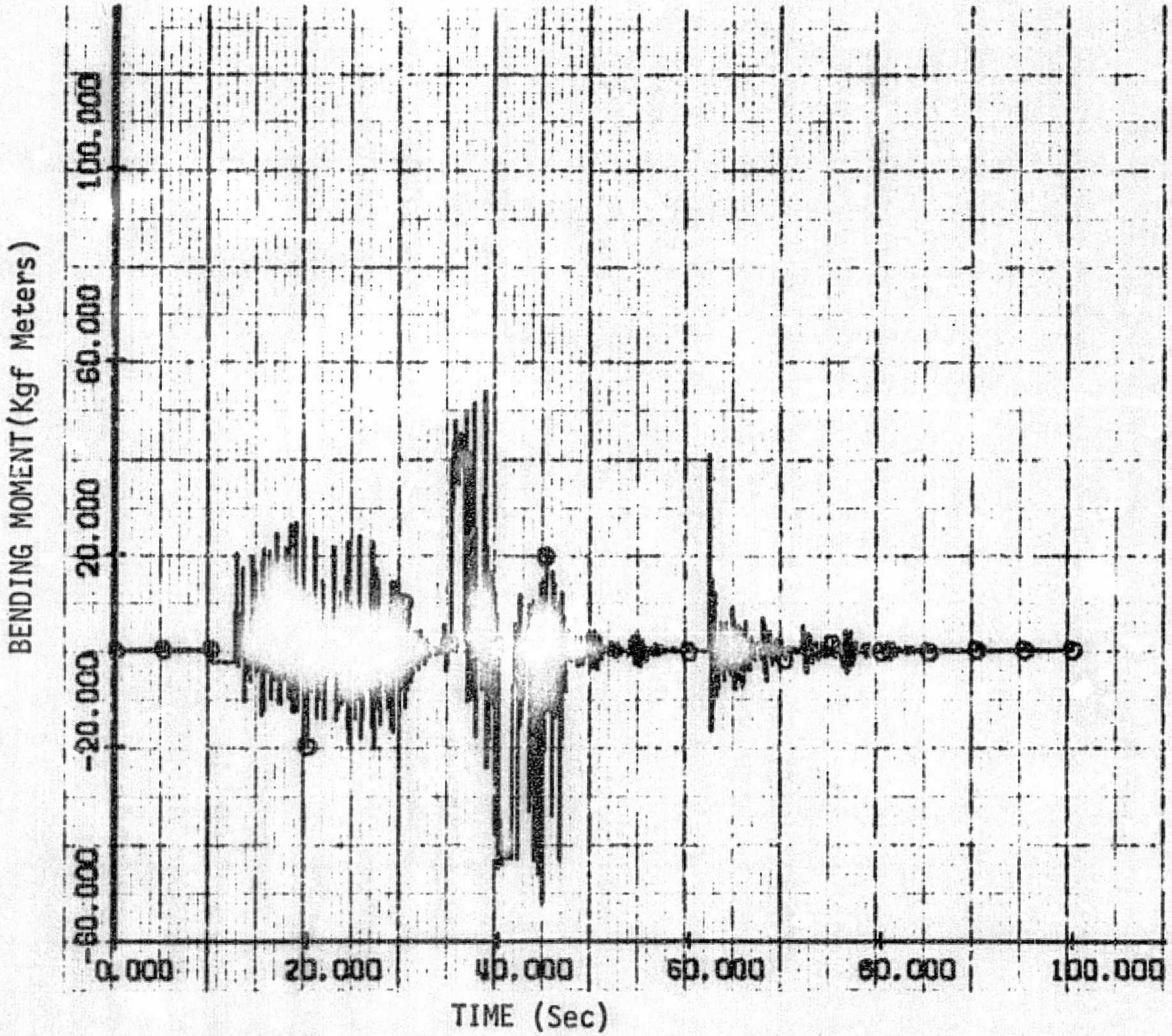


Figure 2R-8 Pitch Bending Moment at Station 1109.5 Versus Time
Case RCS-2

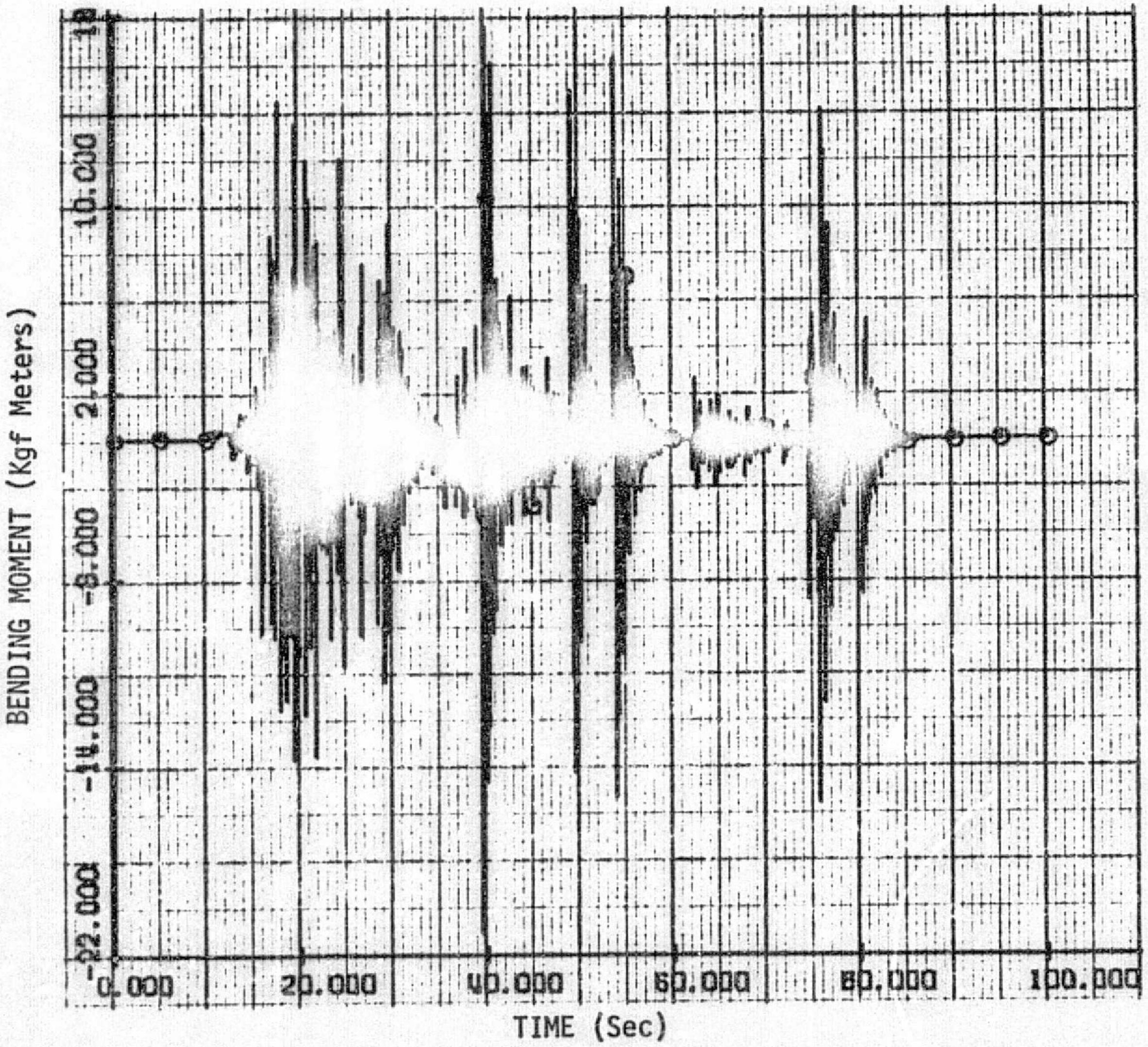


Figure 2R-9 Yaw Bending Moment at Station 1109.5 Versus Time
Case RCS-2

Results for Case 3

Case 3 uses the CSM/LM ascent DAP configuration and is defined by the following three-axis automatic maneuver, followed by an attitude hold:

- Roll angle of rotation 5 deg
- Pitch angle of rotation 7 deg
- Yaw angle of rotation 10 deg
- Deadband 0.5 deg
- Maneuver rate 2 deg
- Attitude hold 80 sec

The response time history is shown in Figures 3R-1 through 3R-13. These results are summarized in Tables 3R-1 and 3R-2.

Table 3R-1 Summary of Results
RCS Case 3

Maximum Bending Moment at Station 1010		
Torsion	5.313E2	Newton Meters
Pitch	1.473E3	Newton Meters
Yaw	2.787E3	Newton Meters
Maximum Bending Moment at Station 1109.5		
Torsion	-1.194E3	Newton Meters
Pitch	6.387E2	Newton Meters
Yaw	5.443E2	Newton Meters
Maximum Angular Rates		
Roll	.84 deg/sec	
Pitch	.90 deg/sec	
Yaw	1.50 deg/sec	

The objective of this run was to demonstrate the automatic capability of the CSM-LM ascent DAP in the performance of an automatic three-axis maneuver and to hold an inertial attitude following the maneuver. The initialization and sequence for this simulation was the same as Case 1 except for the DAP configuration. In this case the configuration digit of Register 1 (Noun 46) was set to 6 (CSM and LM ascent stage only) during the DAP data load.

The DAP satisfactorily performed the automatic maneuver to the specified attitude and satisfactorily maintained the inertial attitude within the specified deadband. The total fuel consumed during this 100-second simulation was 4.036 pounds (1.83 kg). A summary of the RCS jet activity is contained in Table 3R-2.

The DAP performance for this case was almost identical with that of Case 1. The phase planes, time histories of rates and load plots presented in Figures 3R-1 through 3R-13 were compared with the corresponding figures of Case 1. The corresponding plots were very similar in all cases. The DAP estimates of vehicle inertia for the CSM-LM ascent configuration were slightly more favorable than the CSM-alone case. As a result the jet firings were a little longer thereby reducing the total number of firings. The total number of firings for this case was 66 compared to 88 for Case 1. However, the saving in RCS fuel usage was less than 0.03 pounds. The induced loads were essentially the same in both cases.

TABLE 3R-2

RCS JET ACTIVITY AND FUEL CONSUMPTION SUMMARY FROM TZERO TO TIME = 99.99900

JET	NFIRE	TRCON (SEC)	FUEL (KG)	FUEL (LB)
1	3	.83309	.14469	.31898
2	7	.91545	.16453	.36273
3	3	.83309	.14469	.31898
4	7	.91545	.16453	.36273
5	4	1.49898	.25824	.56932
6	8	1.46704	.25885	.57067
7	4	1.49898	.25824	.56932
8	8	1.46704	.25885	.57067
13	5	.21286	.04330	.09547
14	6	.21889	.04582	.10101
15	5	.21286	.04330	.09547
16	6	.21889	.04582	.10101
TOTAL ALL JETS	66	10.29262	1.83086	4.03636

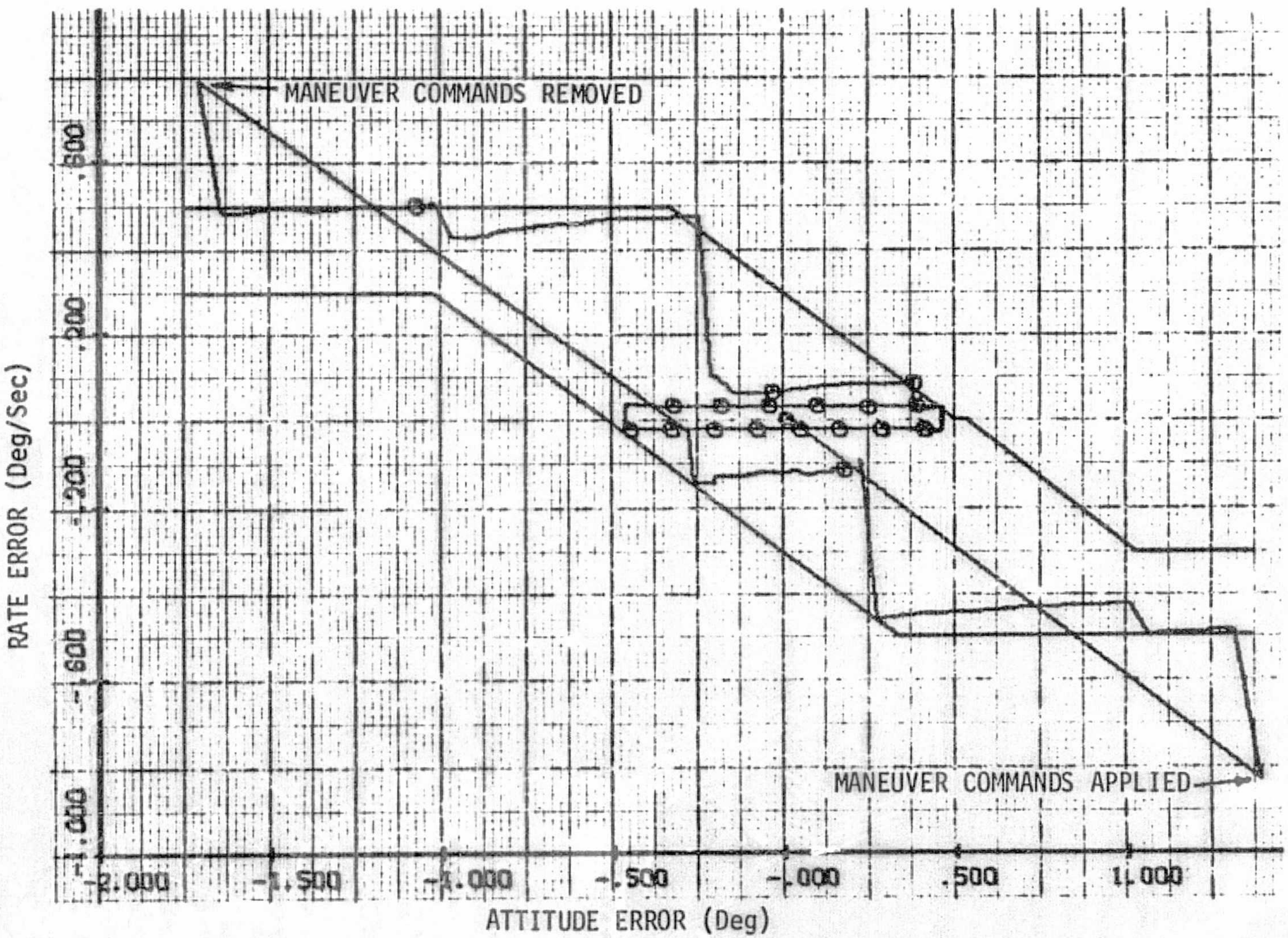


Figure 3R-1   Roll Axis Phase Plane   Case 3

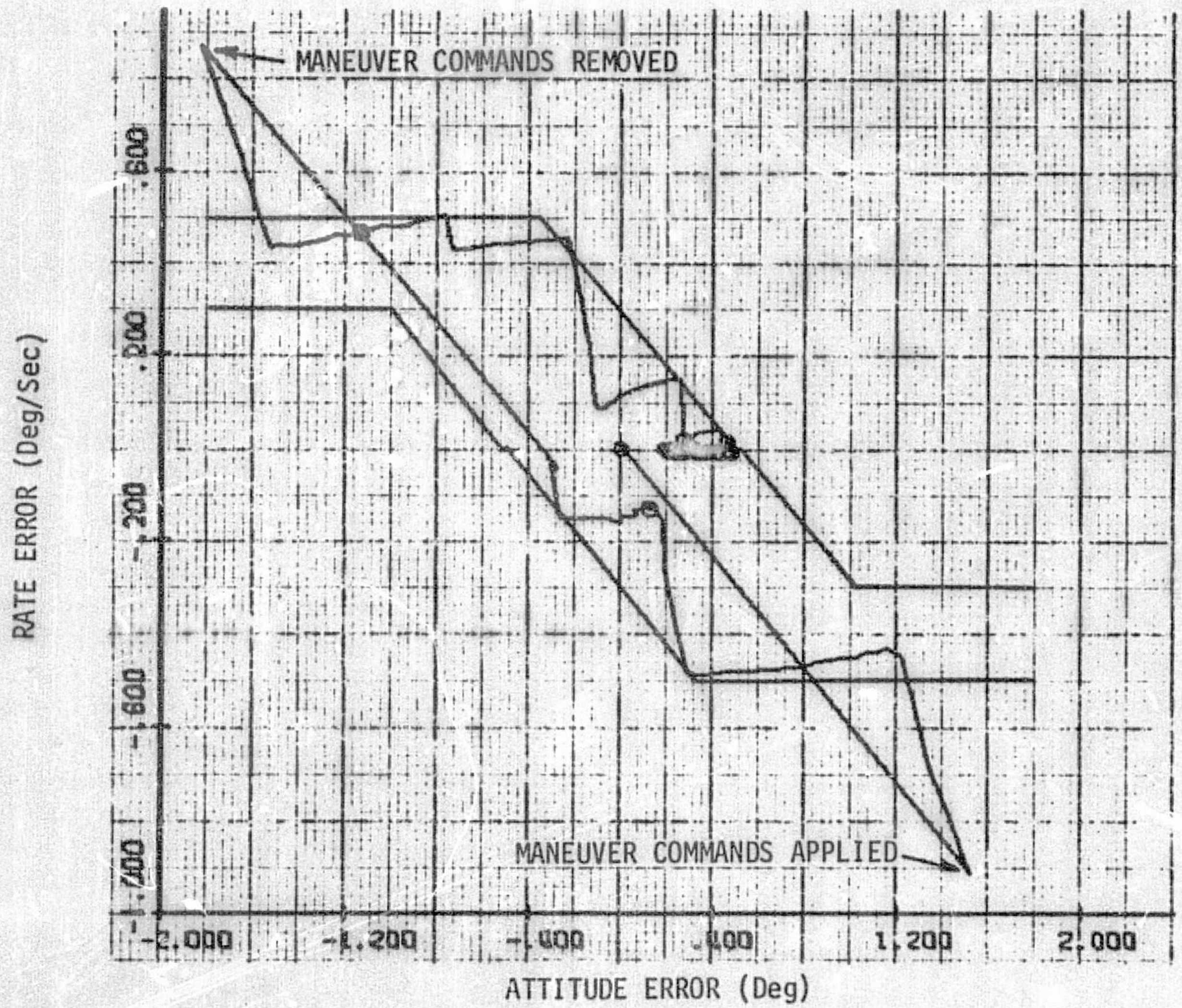


Figure 3R-2   Pitch Axis Phase Plane   Case 3

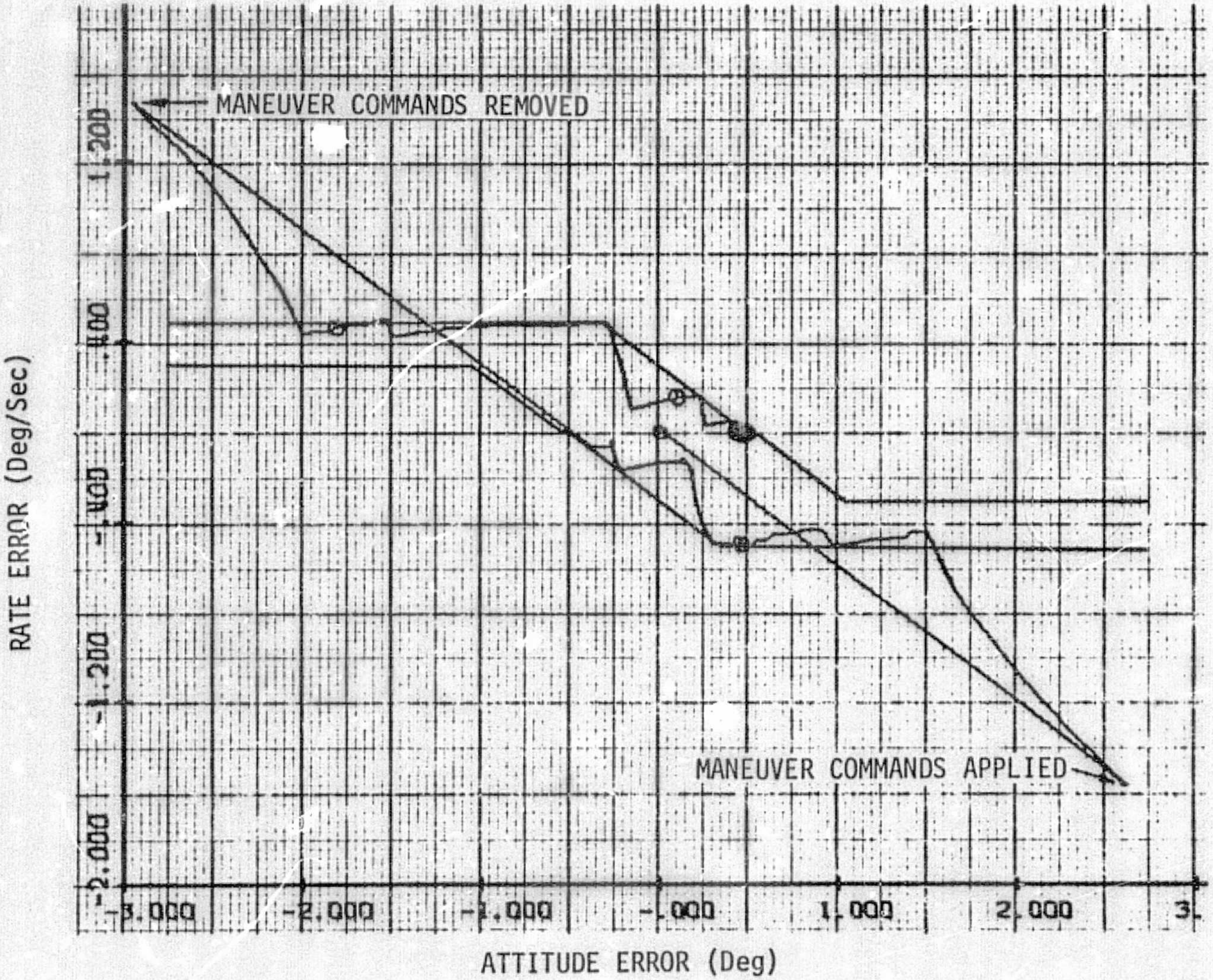


Figure 3R-3 Yaw Axis Phase Plane Case 3

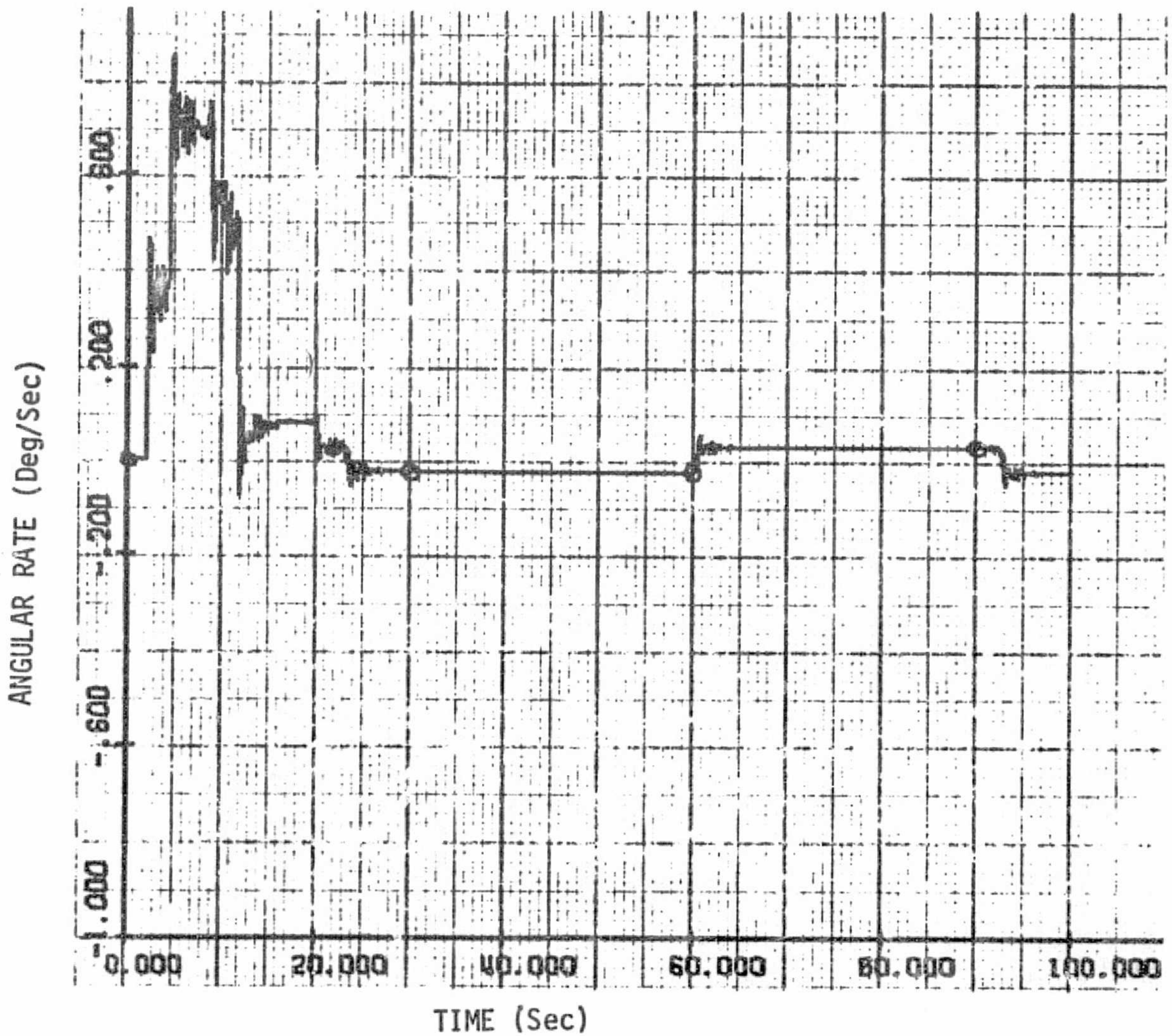


Figure 3R- 4   X-Axis Angular Rate Versus Time
Case 3

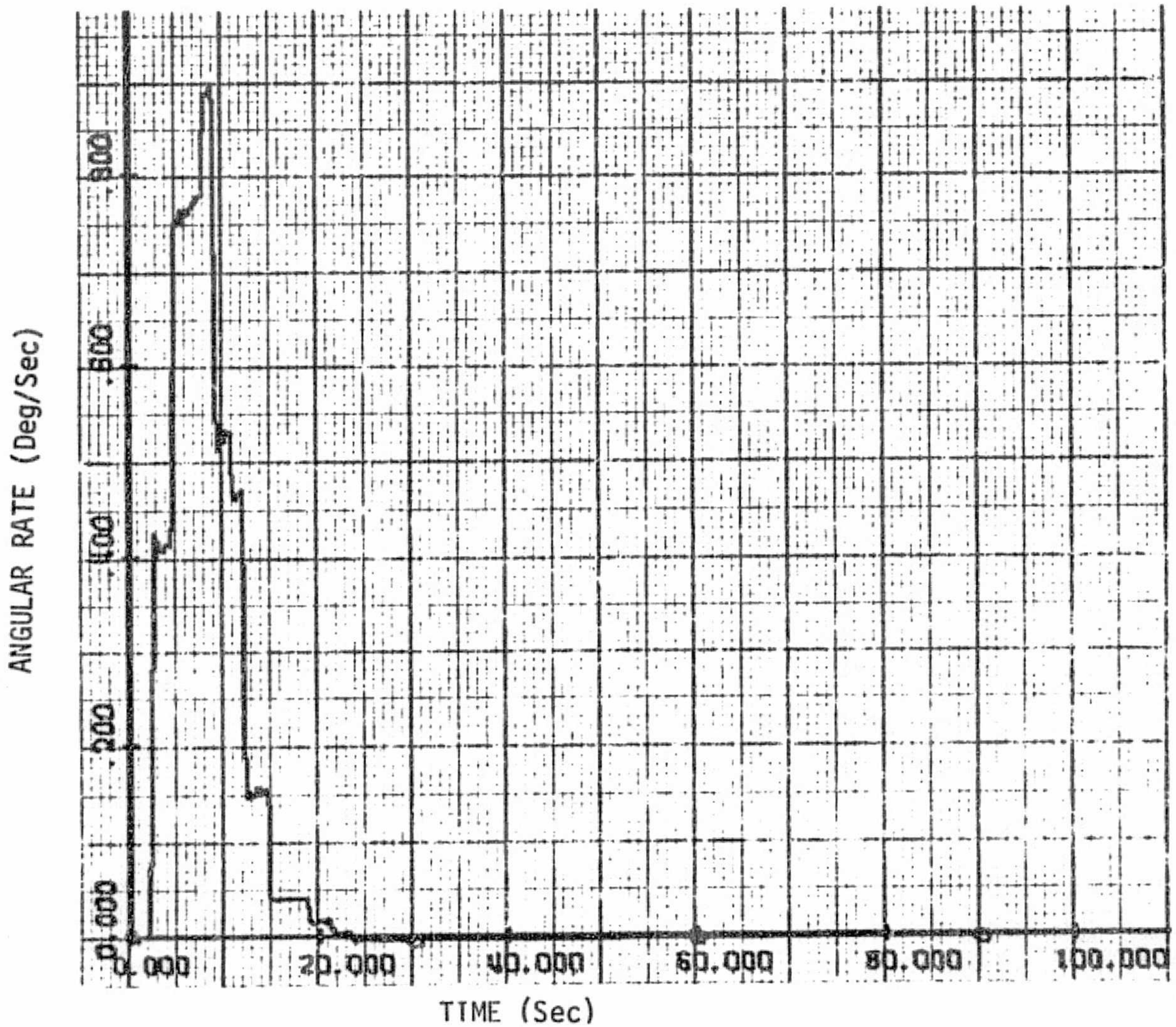


Figure 3R-5 Y-Axis Angular Rate Versus Time
Case 3

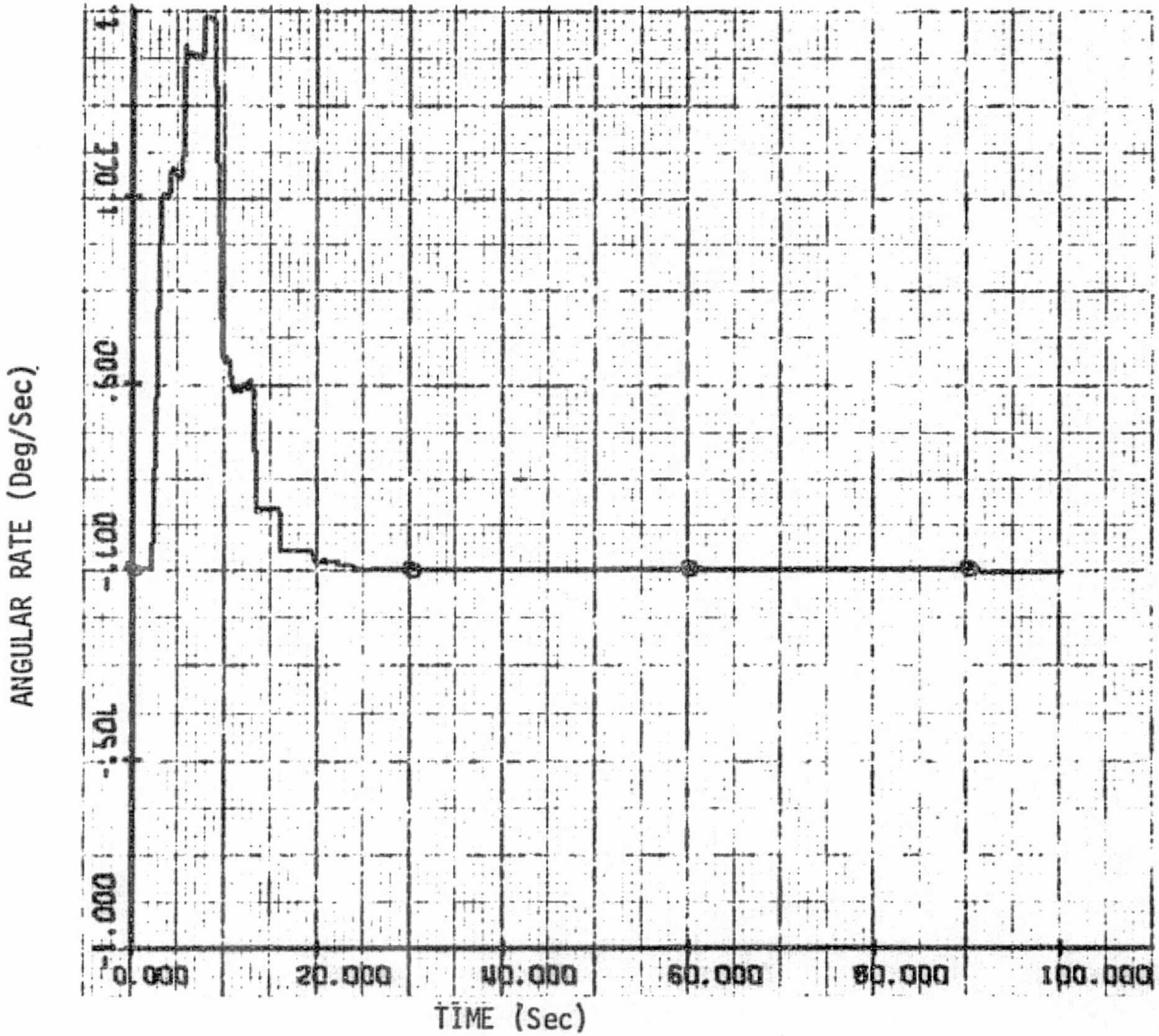


Figure 3R-6   Z-Axis Angular Rate Versus Time
Case 3

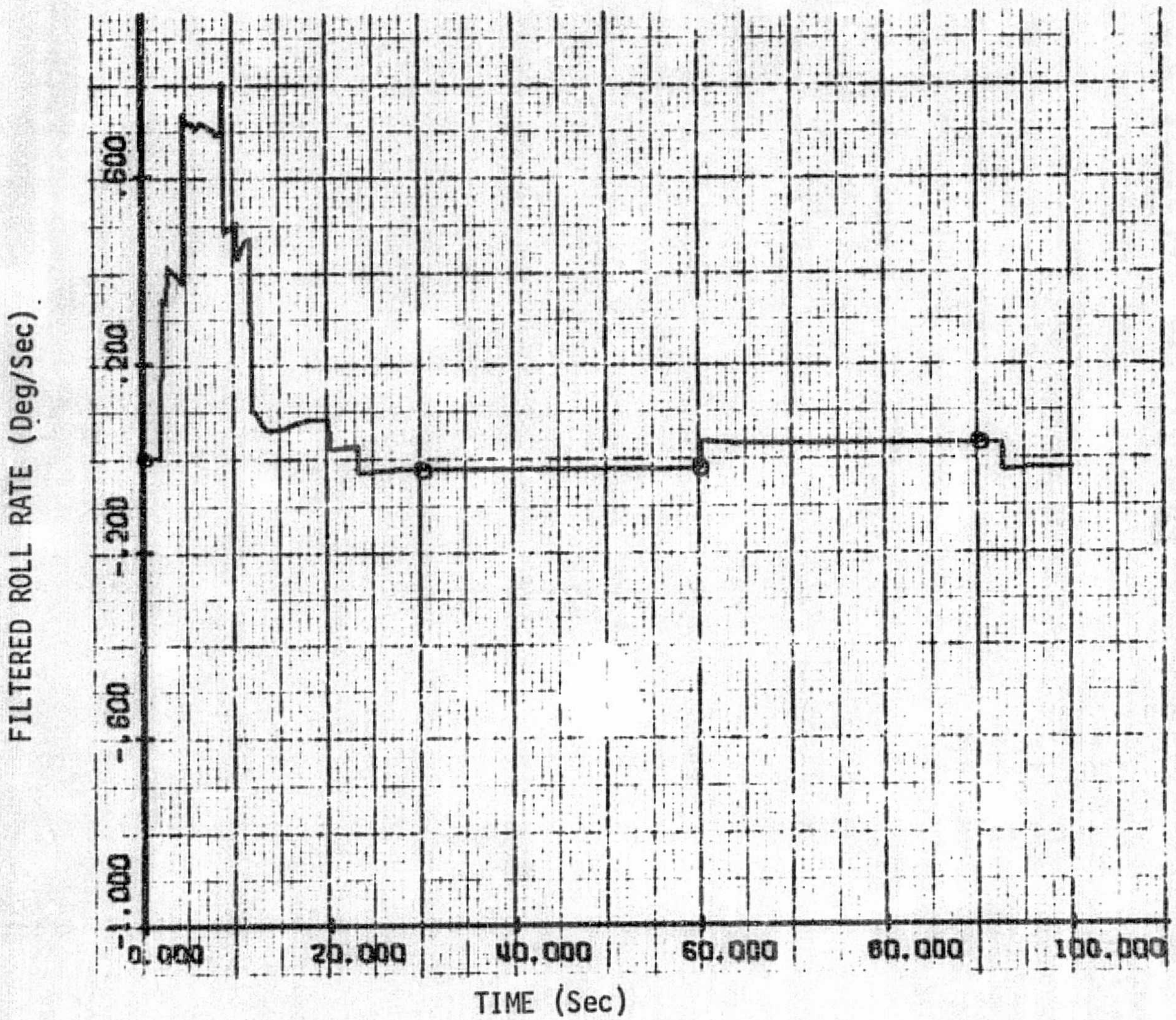


Figure 3R-7 Filtered Roll Rate versus Time Case 3

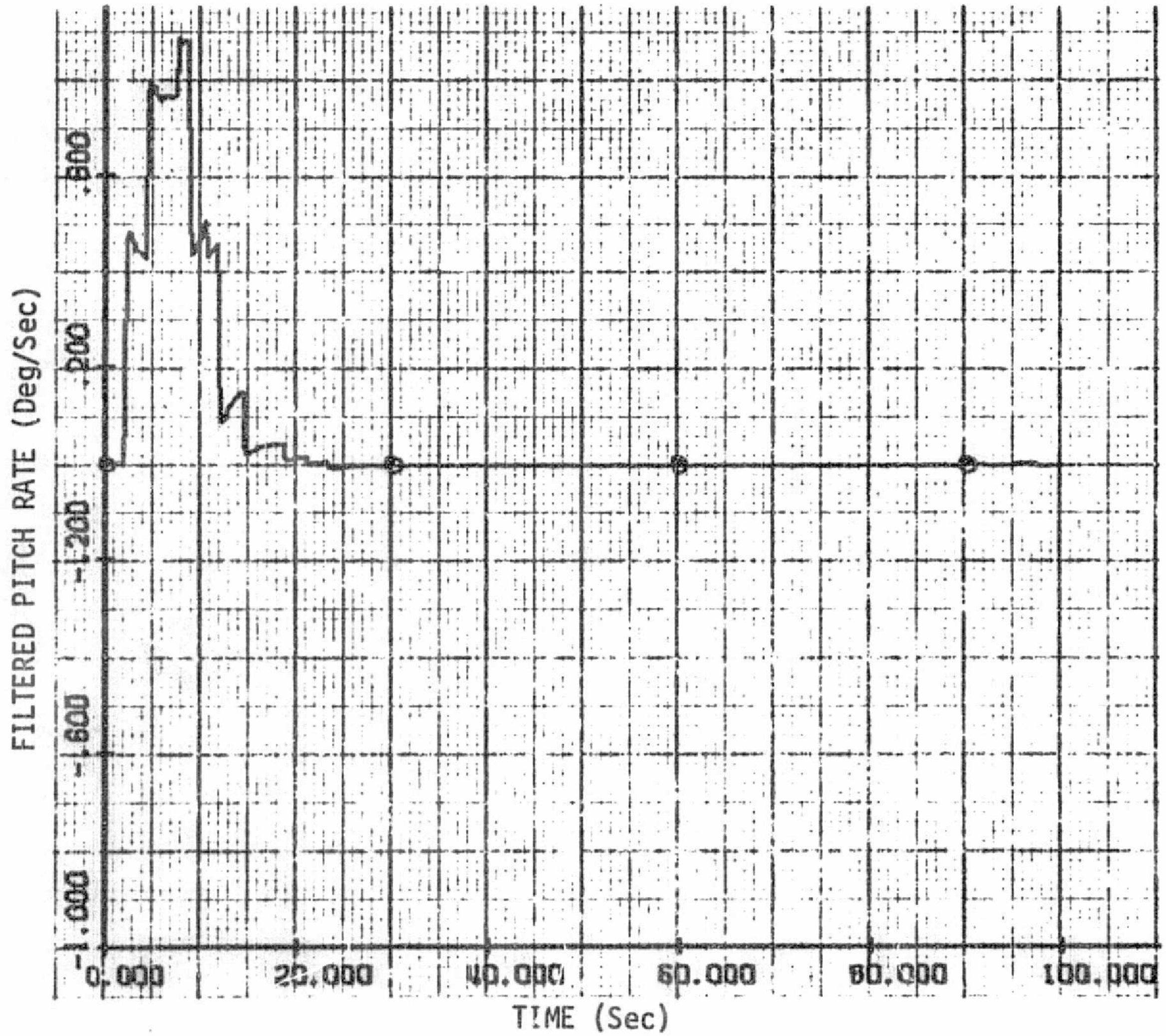


Figure 3R-8 Filtered Pitch Rate versus Time Case 3

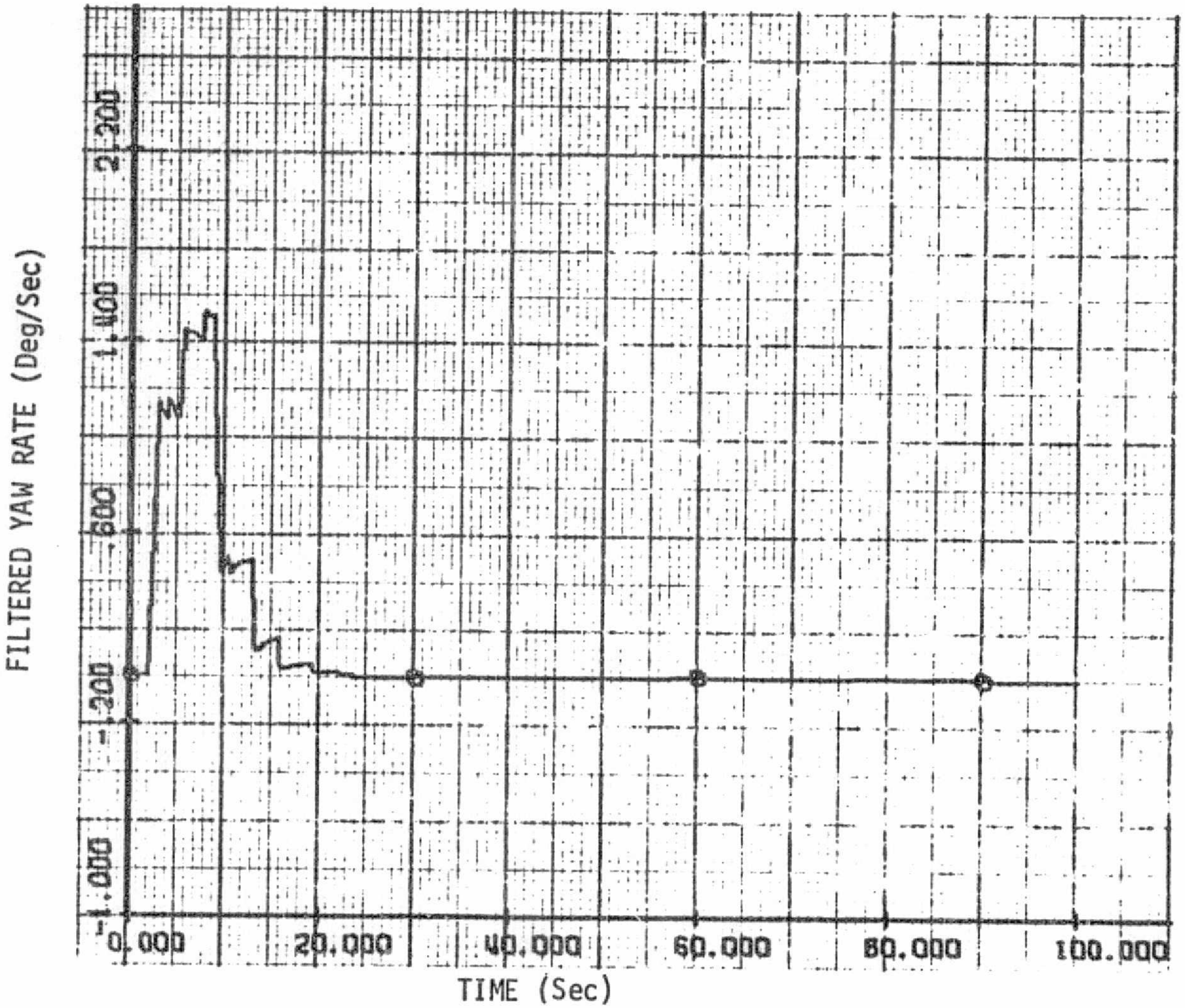


Figure 3R-9 Filtered Yaw Rate versus Time Case 3

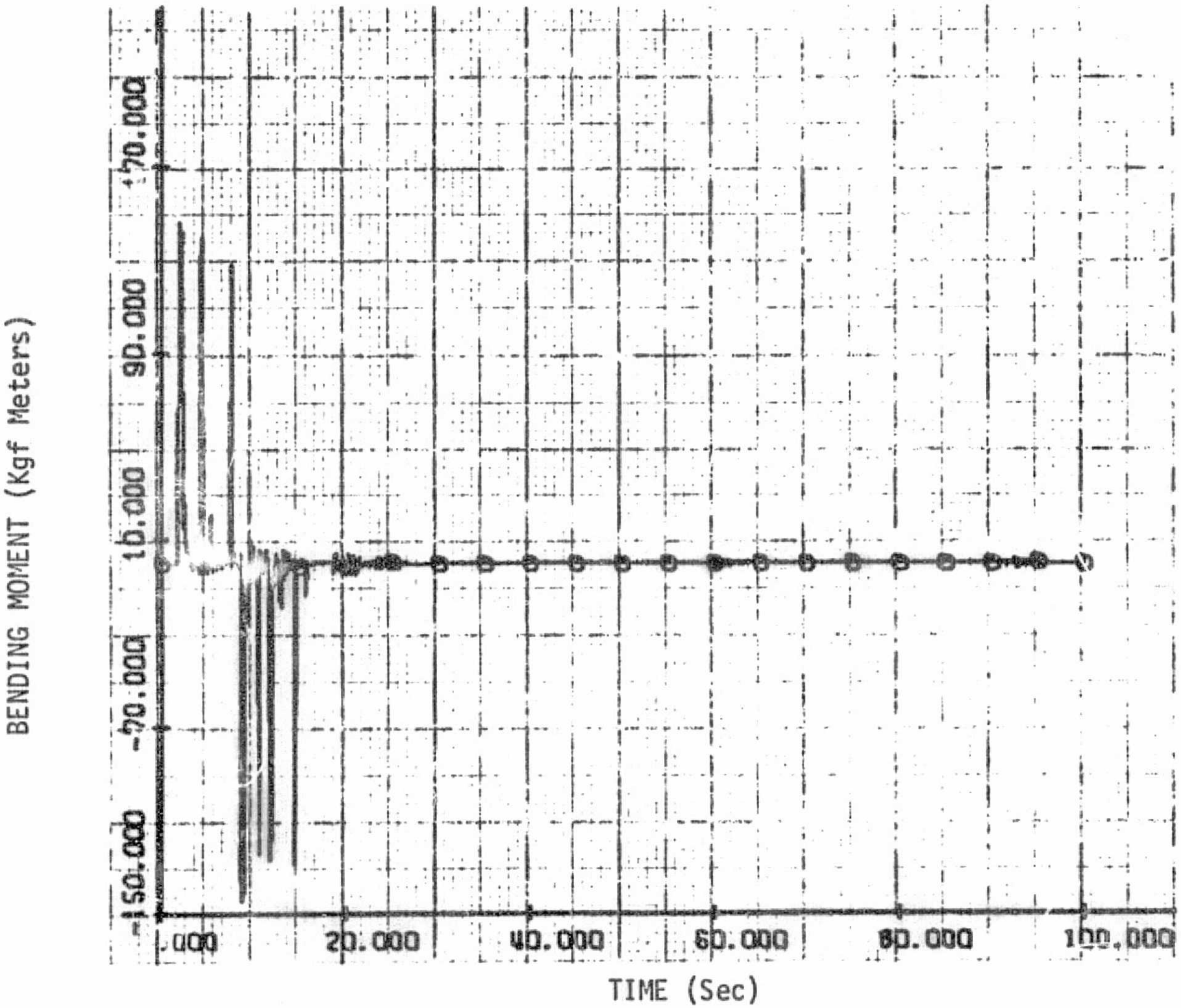


Figure 3R-10 Pitch Bending Moment at Station 1010 versus Time Case 3

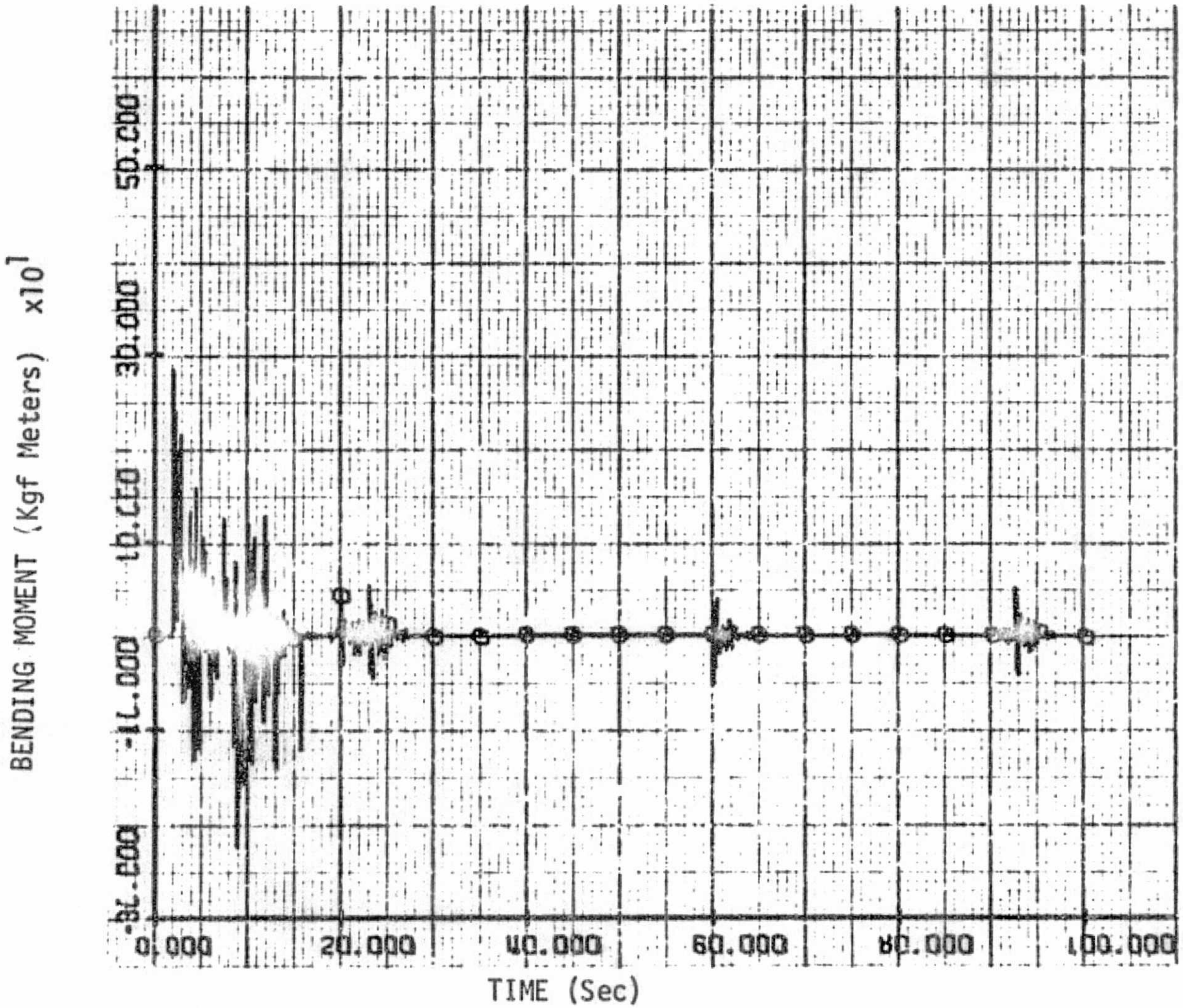


Figure 3R-11 Yaw Bending Moment at Station 1010 versus Time Case 3

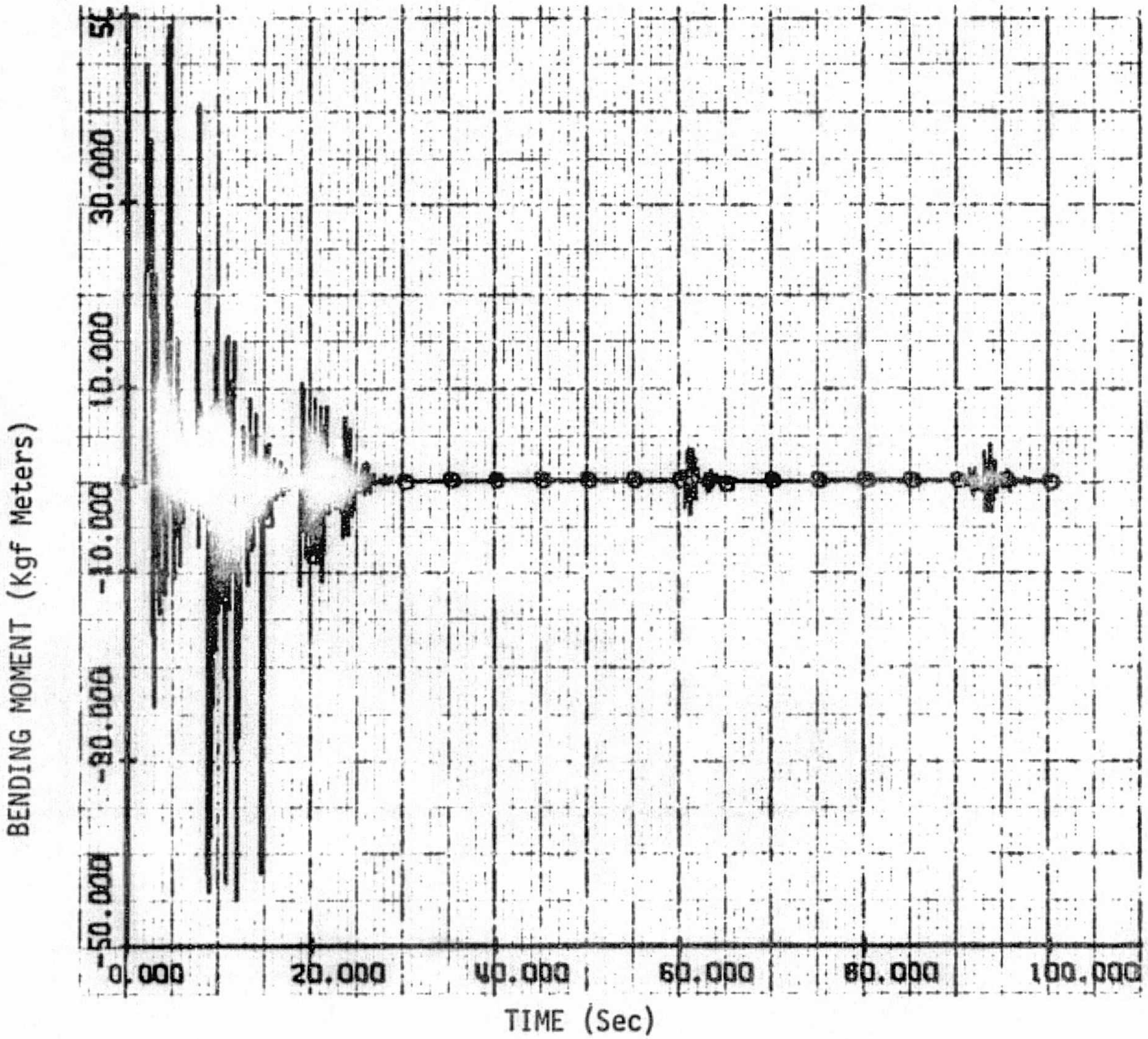


Figure 3R-12 Pitch Bending Moment at Station 1109.5 versus Time Case 3

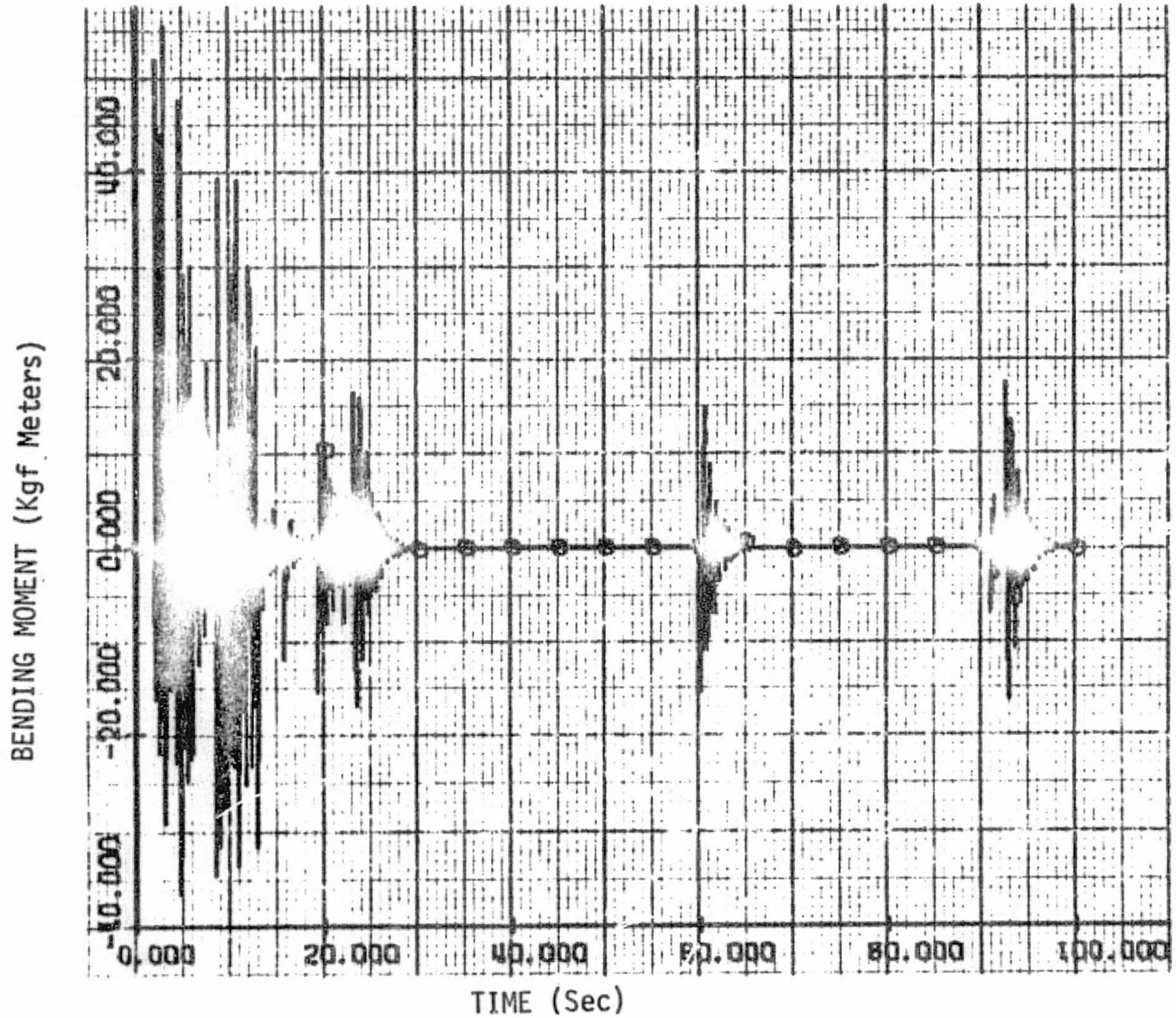


Figure 3R-13 Yaw Bending Moment at Station 1109.5 versus Time Case 3

Results for Case 4

Case 4 is defined by the following maneuver:

- Four jet X-translation THC out of detent — 20 sec
- Positive pitch rotation RHC out of detent — 5 sec
- Attitude hold — 60 sec
- Deadband — 0.5 deg

Simulated response time histories are presented in Figures 4R-1 through 4R-9. Tabulated summaries are shown in Tables 4R-1 and 4R-2.

Table 4R-1 Summary of Results
RCS Case 4

Maximum Bending Moment at Station 1010		
Torsion	2.389E2	Newton Meters
Pitch	-1.335E3	Newton Meters
Yaw	-1.207E3	Newton Meters
Maximum Bending Moment at Station 1109.5		
Torsion	1.546E3	Newton Meters
Pitch	-6.875E2	Newton Meters
Yaw	2.662E2	Newton Meters
Maximum Angular Rate Magnitudes		
Roll	.13	deg/sec
Pitch	2.1	deg/sec
Yaw	.11	deg/sec

The objective of this run was to demonstrate the CSM-LM ascent DAP capability to perform a manual +X translation with automatic attitude hold and to perform a positive pitch rotation with the rotational hand controller. The initialization and sequence for this simulation was the same as Case 2 except for the DAP configuration.

The DAP responded correctly to the THC and RHC commands and satisfactorily maintained attitude control during the periods of manual commands. The total fuel consumed during this 100-second simulation was 31.96 pounds (14.5 kg). A summary of the RCS jet activity is contained in Table 4R-2.

Once again the performance of the CSM-LM ascent DAP was almost identical to that of the CSM-alone DAP. Comparisons of the data presented in Figures 4R-1 through 4R-9 with the corresponding data presented in Figures 2R-1 through 2R-9 show the similarity of the two runs. There were 25 fewer jet firings in Case 4 than in Case 2; however, the difference in propellant usage was only 0.11 kg. The duty cycles of Jets 2 and 5 for the X-axis translation were identical to those of Case 2. Further, the induced loads for the two cases were essentially the same.

TABLE 4R-2

RCS JET ACTIVITY AND FUEL CONSUMPTION SUMMARY FROM TZERO TO TIME = 99.99900

JET	NFIRE	TRCON (SEC)	FUEL (KG)	FUEL (LB)
1	10	22.02971	3.72219	8.20602
2	80	19.28383	3.36488	7.41830
3	10	2.02971	.35653	.78602
4	17	2.01570	.36465	.80393
5	36	19.20229	3.28530	7.24285
6	2	20.00825	3.37004	7.42966
8	1	.01112	.00337	.00743
13	2	.02886	.00785	.01731
14	2	.02225	.00674	.01485
15	2	.02886	.00785	.01731
16	2	.02225	.00674	.01485
TOTAL ALL JETS	164	84.68284	14.49615	31.95853

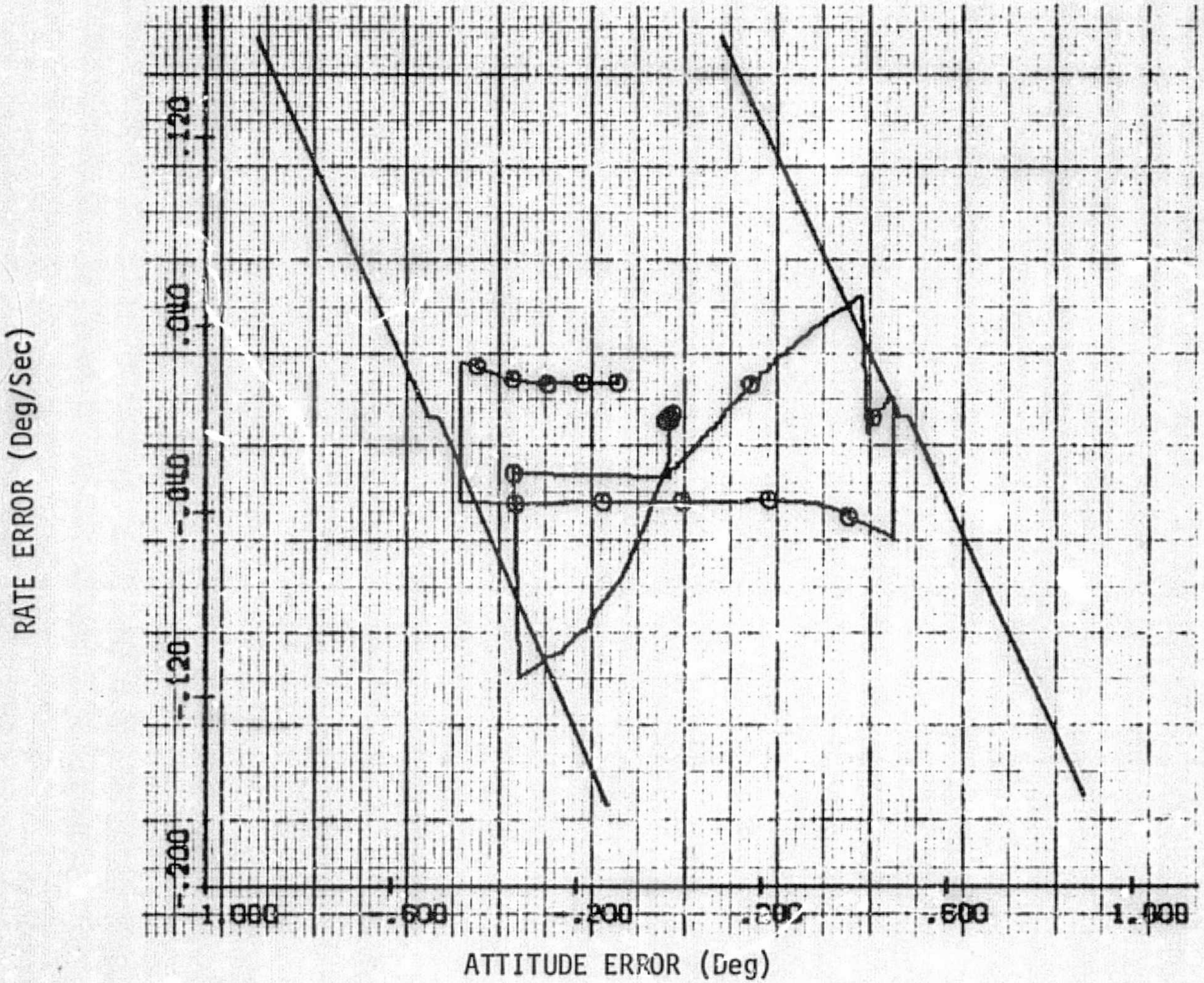


Figure 4R-1 Roll Axis Phase Plane Case 4

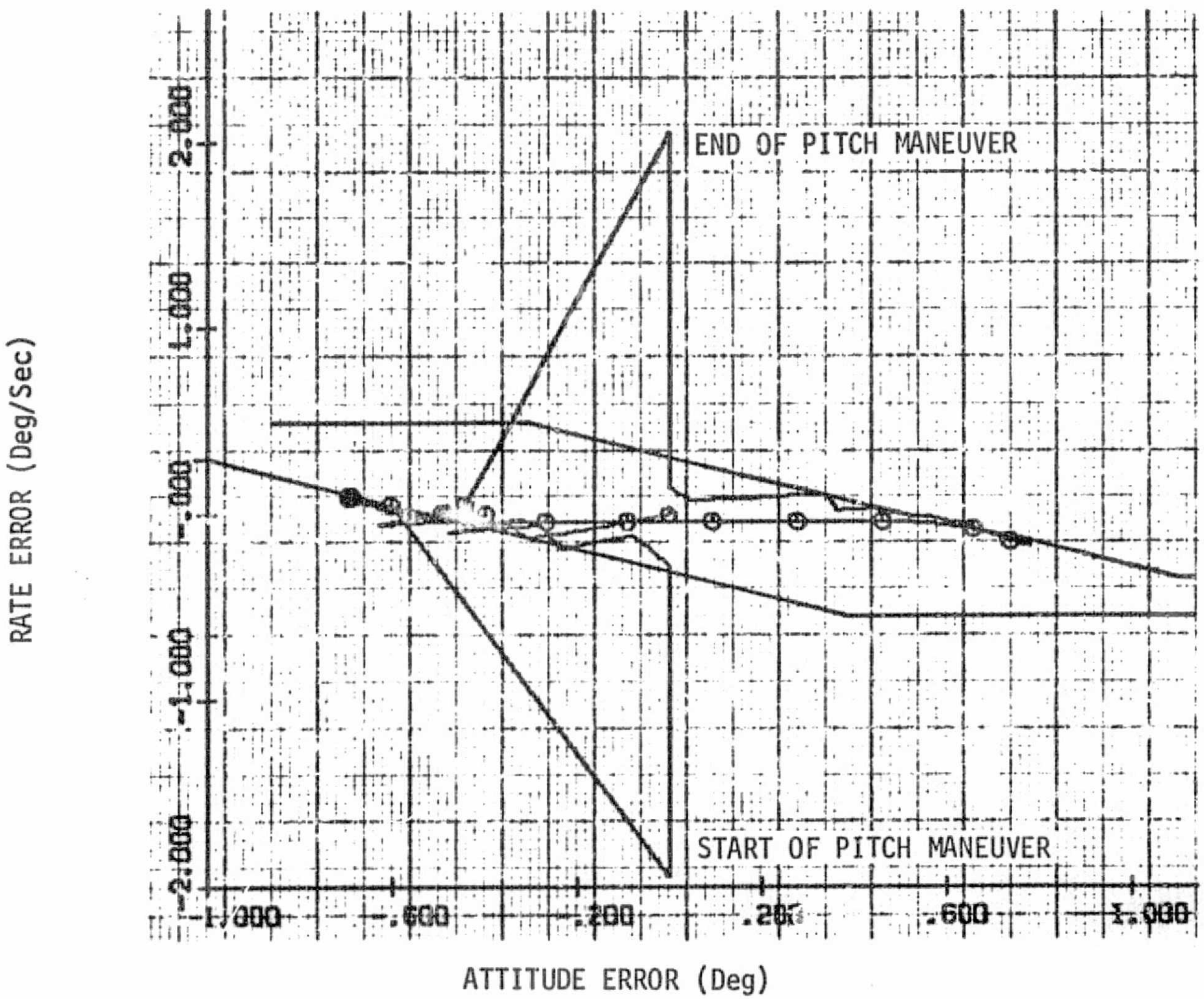


Figure 4R-2 Pitch Axis Phase Plane Case 4

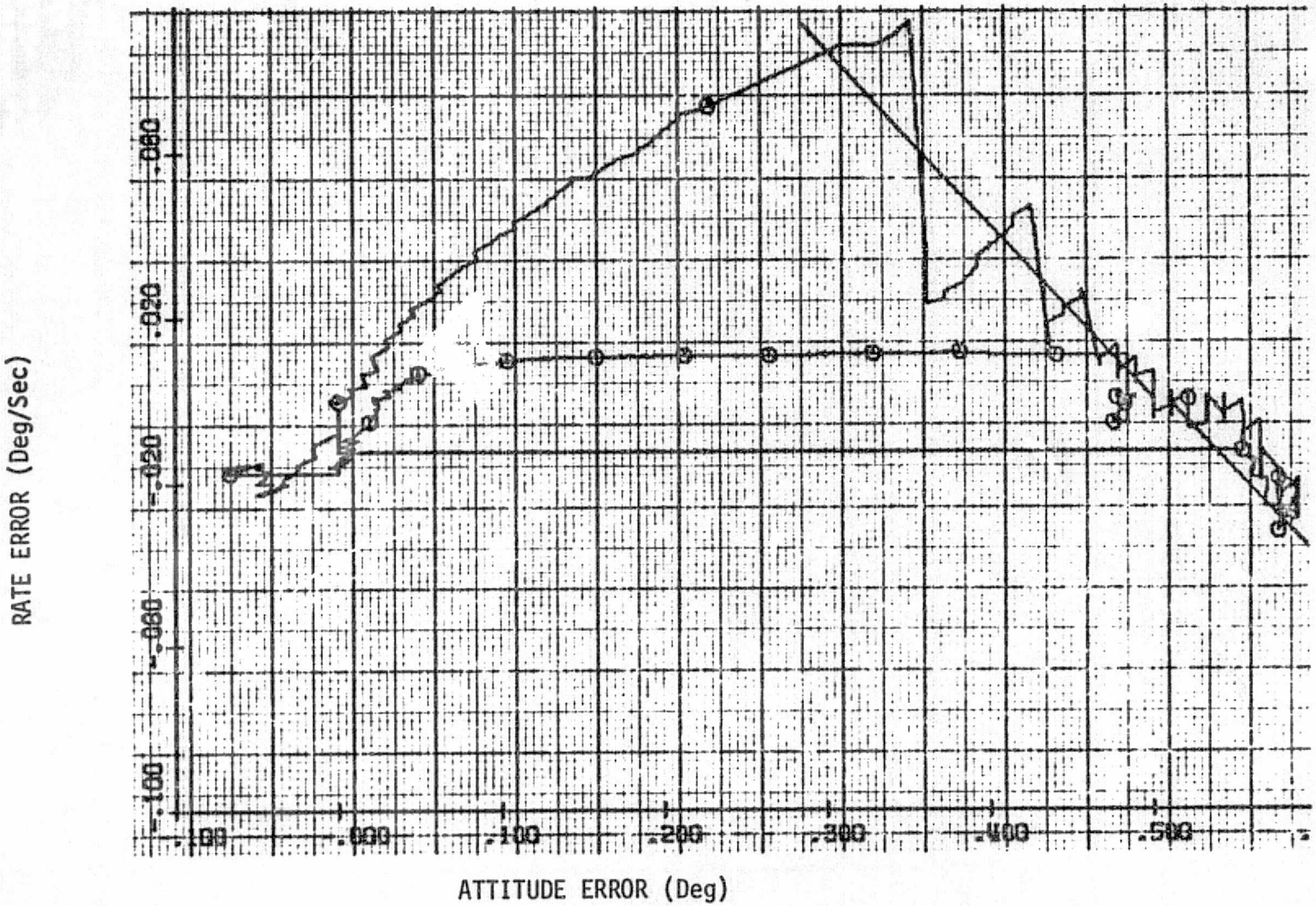


Figure 4R-3 Yaw Axis Phase Plane   Case 4

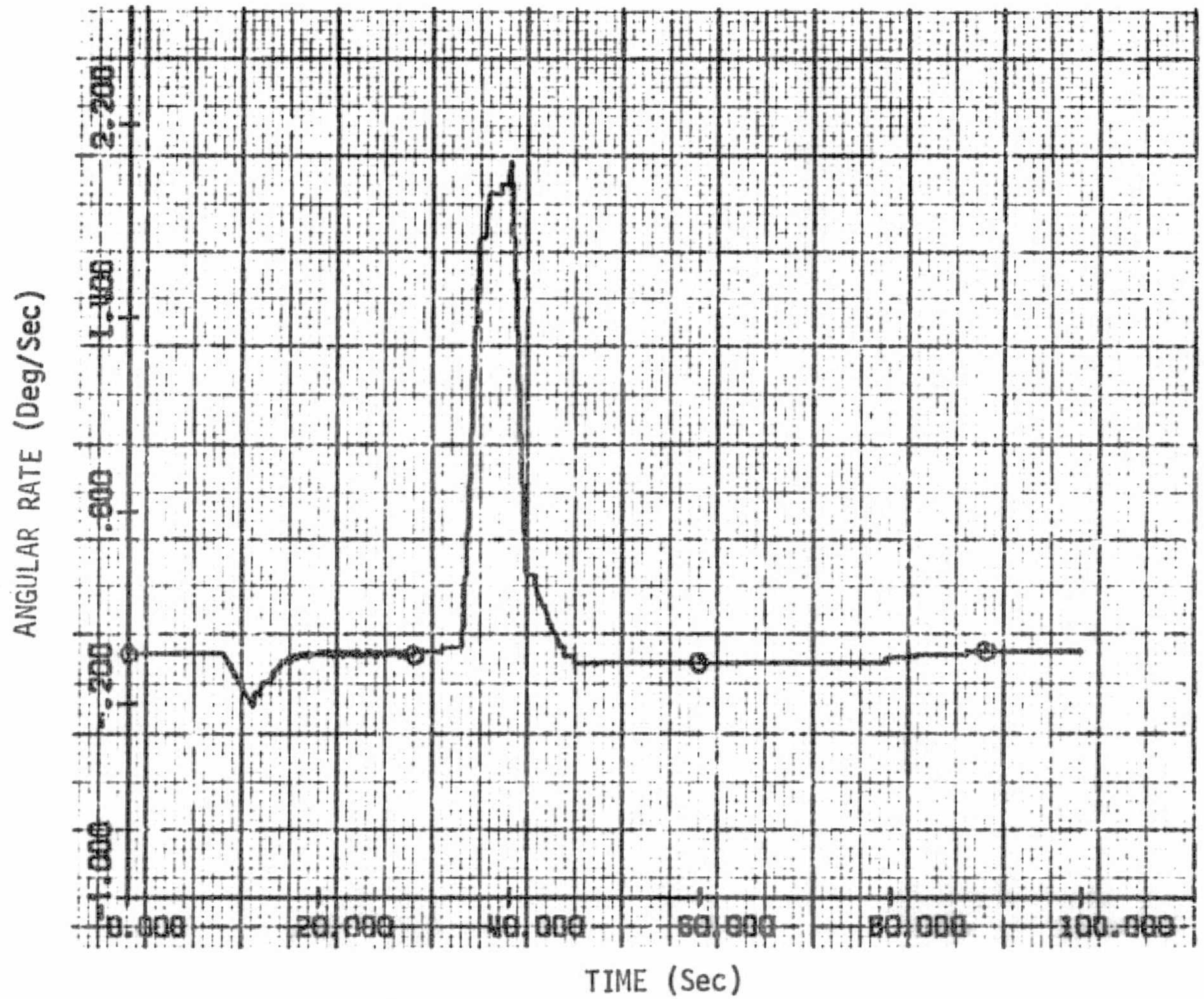


Figure 4R-4 Y-Axis Angular Rate Versus Time
Case RCS-4

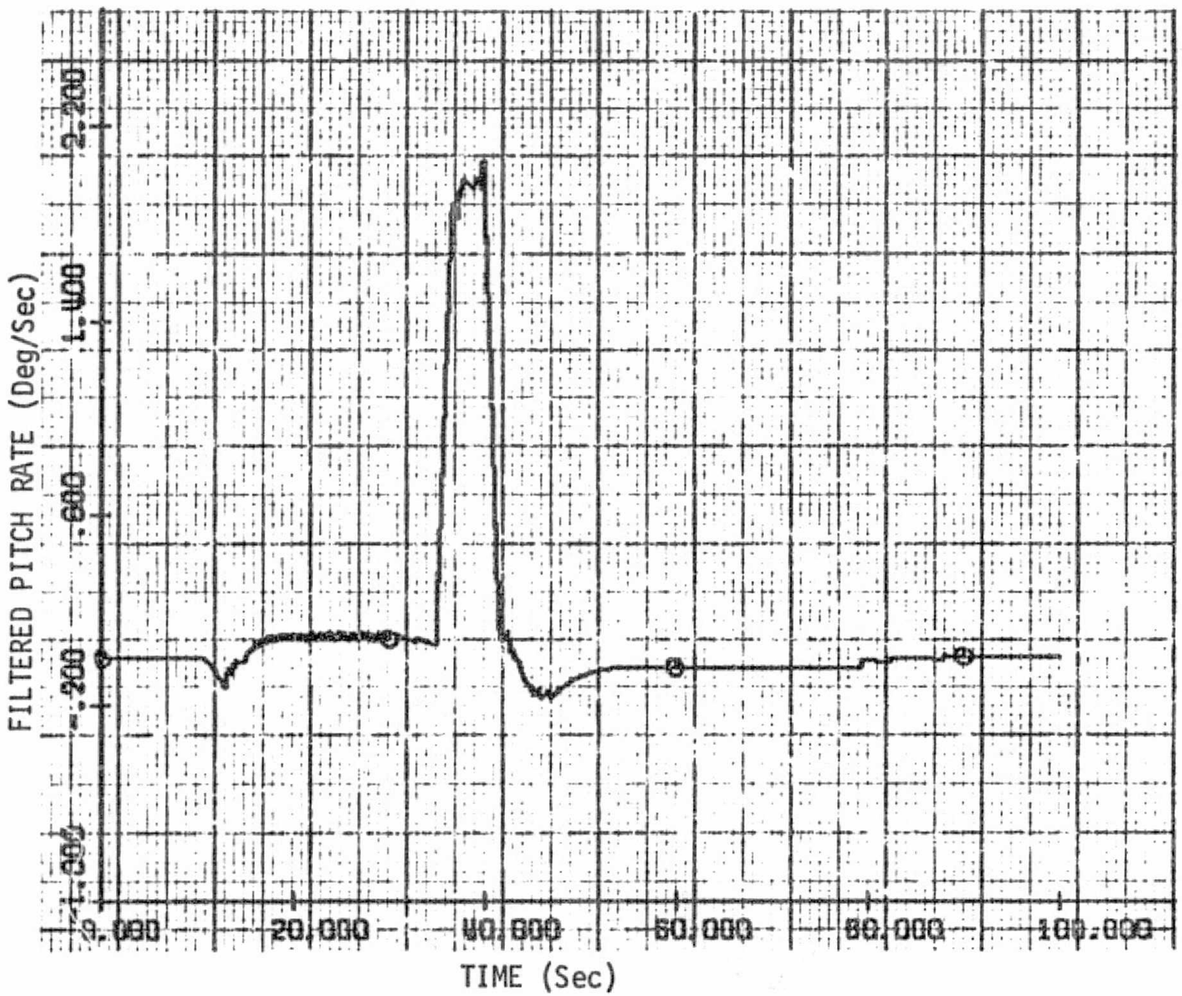


Figure 4R-5 Filtered Pitch Rate Versus Time Case 4

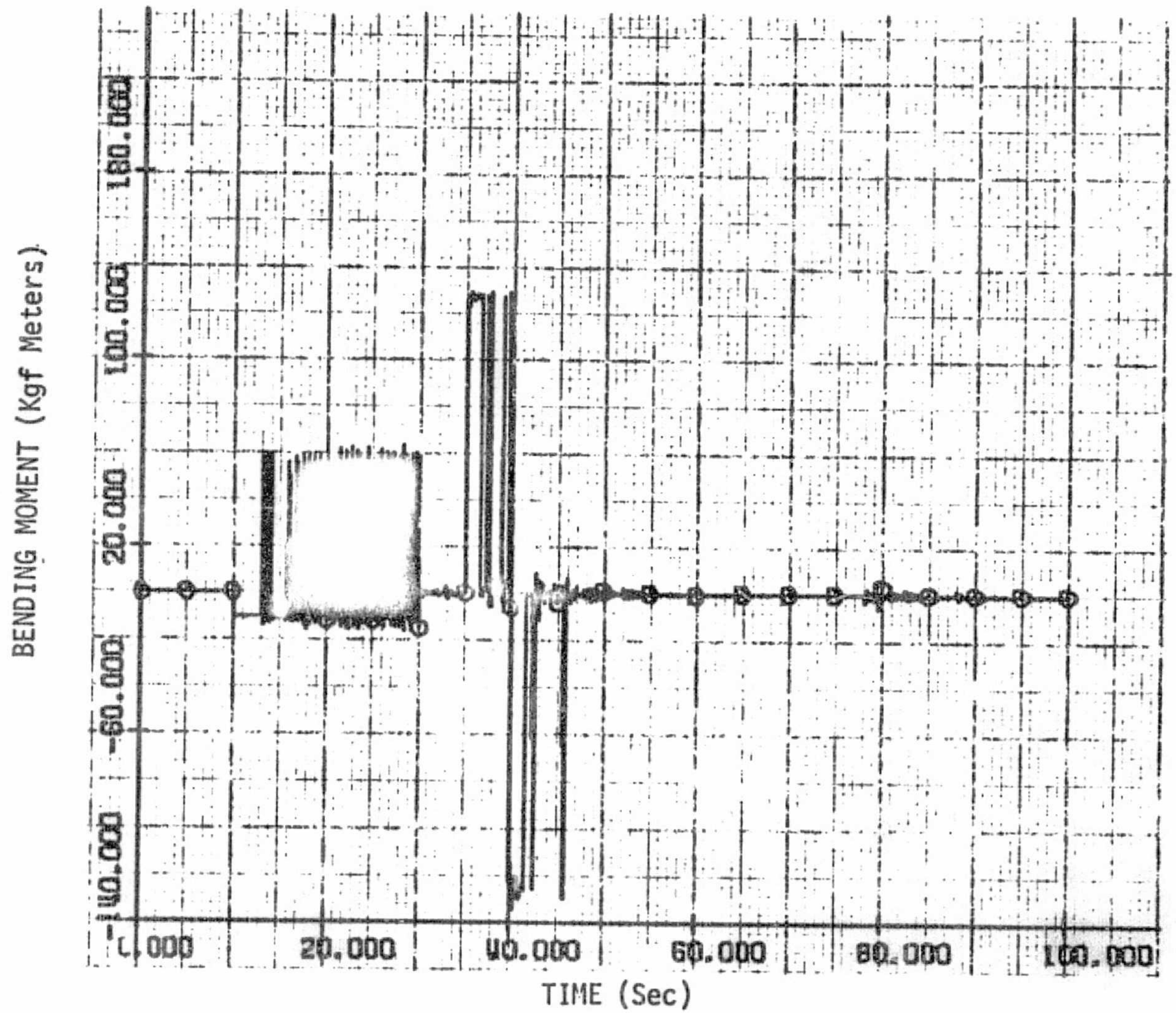


Figure 4R-6 Pitch Bending Moment at Station 1010 Versus Time
Case RCS-4

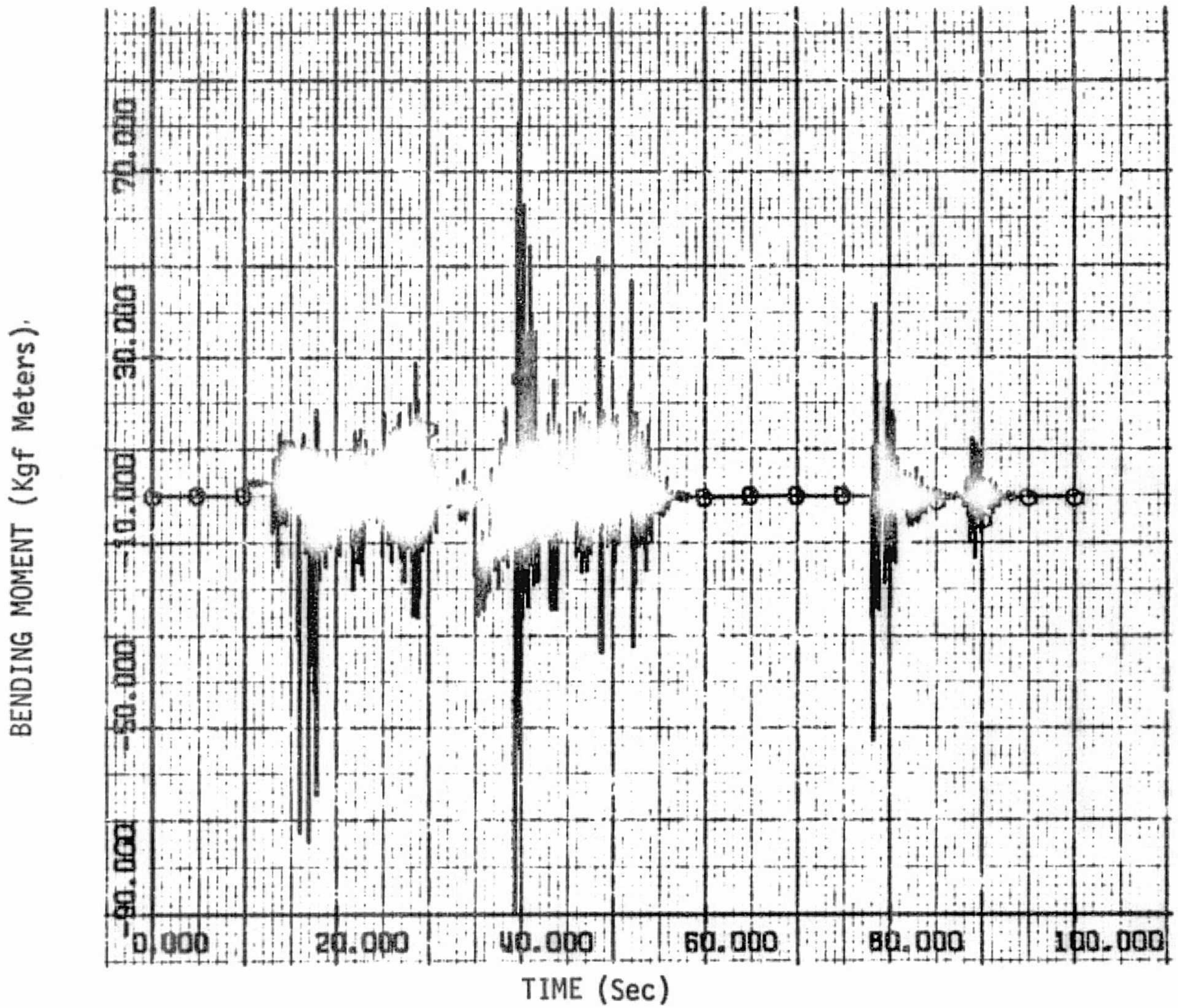


Figure 4R- 7 Yaw Bending Moment at Station 1010 Versus Time
Case RCS -4

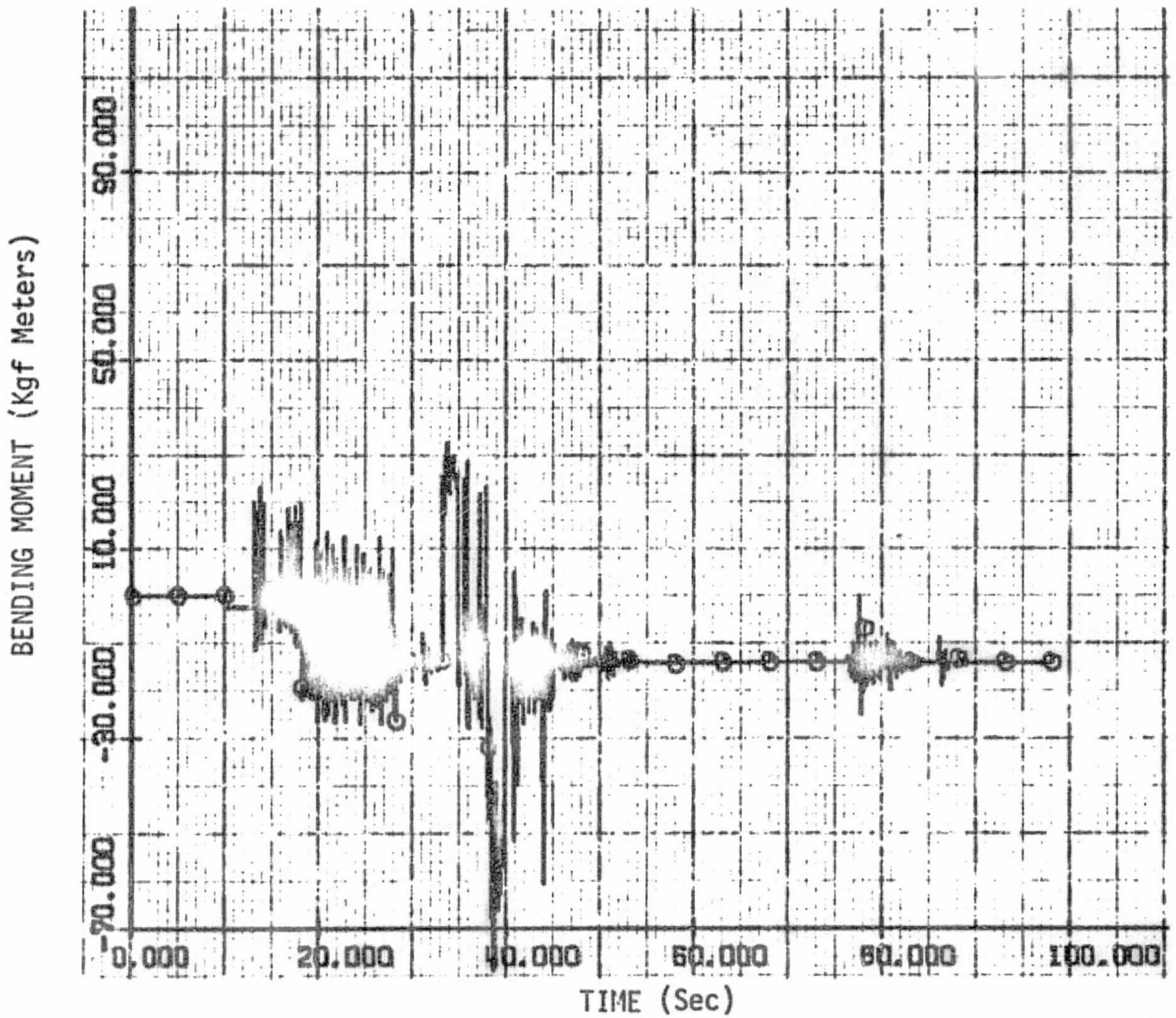


Figure 4R- 8 Pitch Bending Moment at Station 1109.5 Versus Time
Case RCS -4

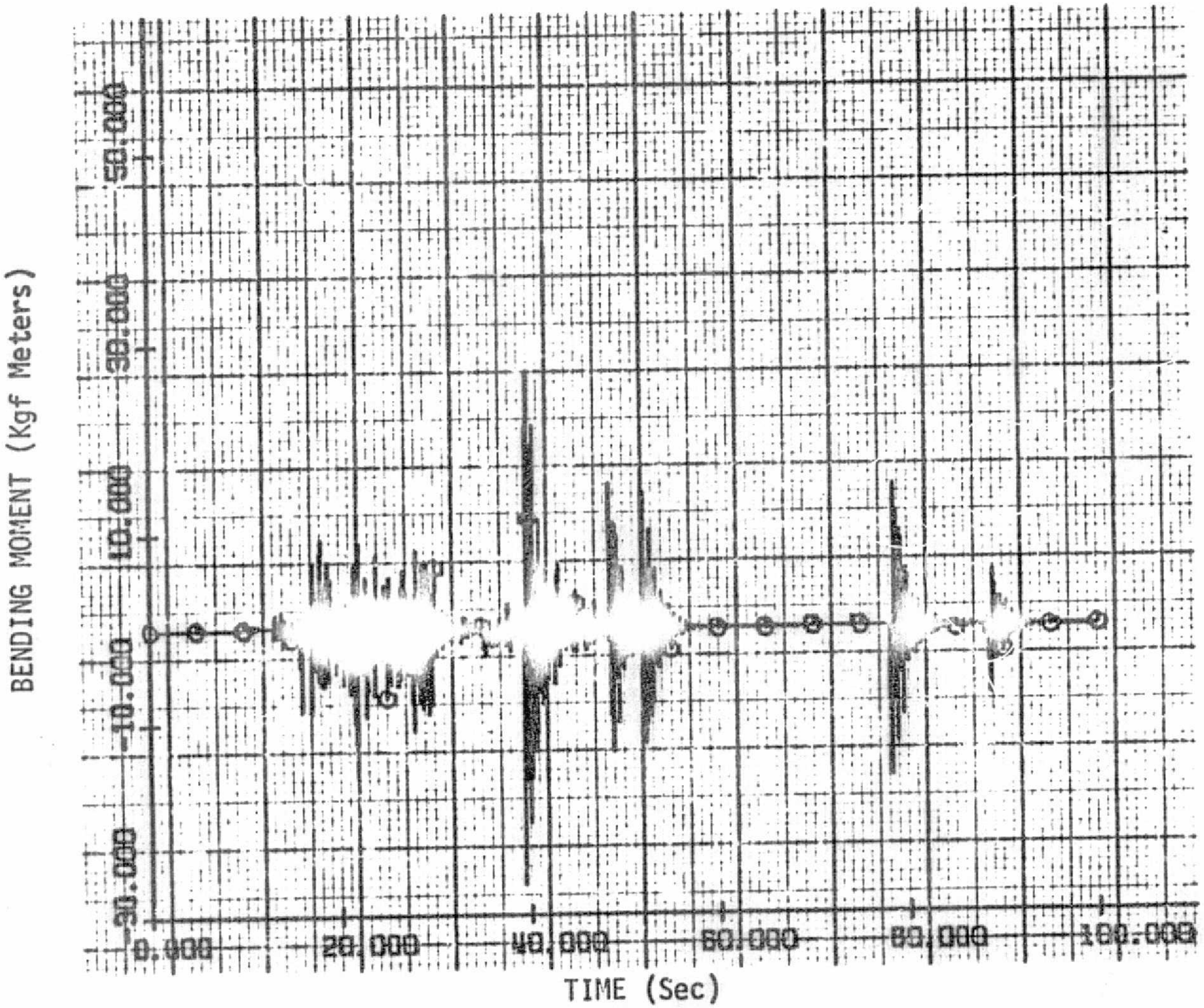


Figure 4R- 9 Yaw Bending Moment at Station 1109.5 Versus Time
Case RCS -4

4. TVC AUTOPILOT TEST RESULTS

4.1 INTRODUCTION

The TVC Autopilot was tested to those conditions described in Reference 3. The mission phases of interest are the planned rendezvous burns and the shaping burn prior to deorbit. Results of frequency analyses using the CSM DAP are presented in Reference 7. The second phase of testing was performed as a time domain response analysis using the SLFS (Skylab Functional Simulator), documented in References 5 and 6, and it is those results which are presented herein.

The simulation cases defined to cover the general conditions are outlined below:

Case 1	CSM Alone (LM-OFF) Gains: ΔV = 30 ft/sec CSM/DM Heavy
Case 2	CSM Alone Gains: ΔV = 100 ft/sec CSM/DM Heavy
Case 3	CSM Alone Gains: ΔV = 500 ft/sec CSM/DM Heavy
Case 4	CSM Alone Gains: ΔV = 100 ft/sec CSM/DM Light
Case 5	CSM Alone Gains: ΔV = 500 ft/sec CSM/DM Light

4.2 STABILITY ANALYSIS RESULTS

Results of the frequency-domain analysis indicate that the CSM TVC Autopilot provides more than adequate stability margins. A summary of results without sloshing is presented in Reference 7. The results shown below include effects from rigid body dynamics, thrust misalignment corrector, steering loop, bending and sloshing.

The stability margins are found to be the following:

Gain Margin	Phase Margin
10 db	33 deg

The graphic results for gain in db versus phase are shown in Figure 4-1.

The above stability margins were calculated for the heavy vehicle configuration, i.e., the greater amount of propellant. The heavy configuration was evaluated because the slosh model associated with this propellant loading is more representative of the physical situation of sloshing, compared to the light configuration. In the light configuration, the SPS propellant level is just slightly above the low-level screens located at the lower ends of the SPS sump tanks and these screens would effectively damp slosh of the remaining SPS propellants. The results of the analyses which were presented in Reference 7 indicated that the Gain Margin was 10 db and the Phase Margin was 40 deg when slosh was neglected. This demonstrates the slight destabilizing effect of slosh for this configuration. Nevertheless, the frequency-domain analyses indicate that the stability margins are adequate.

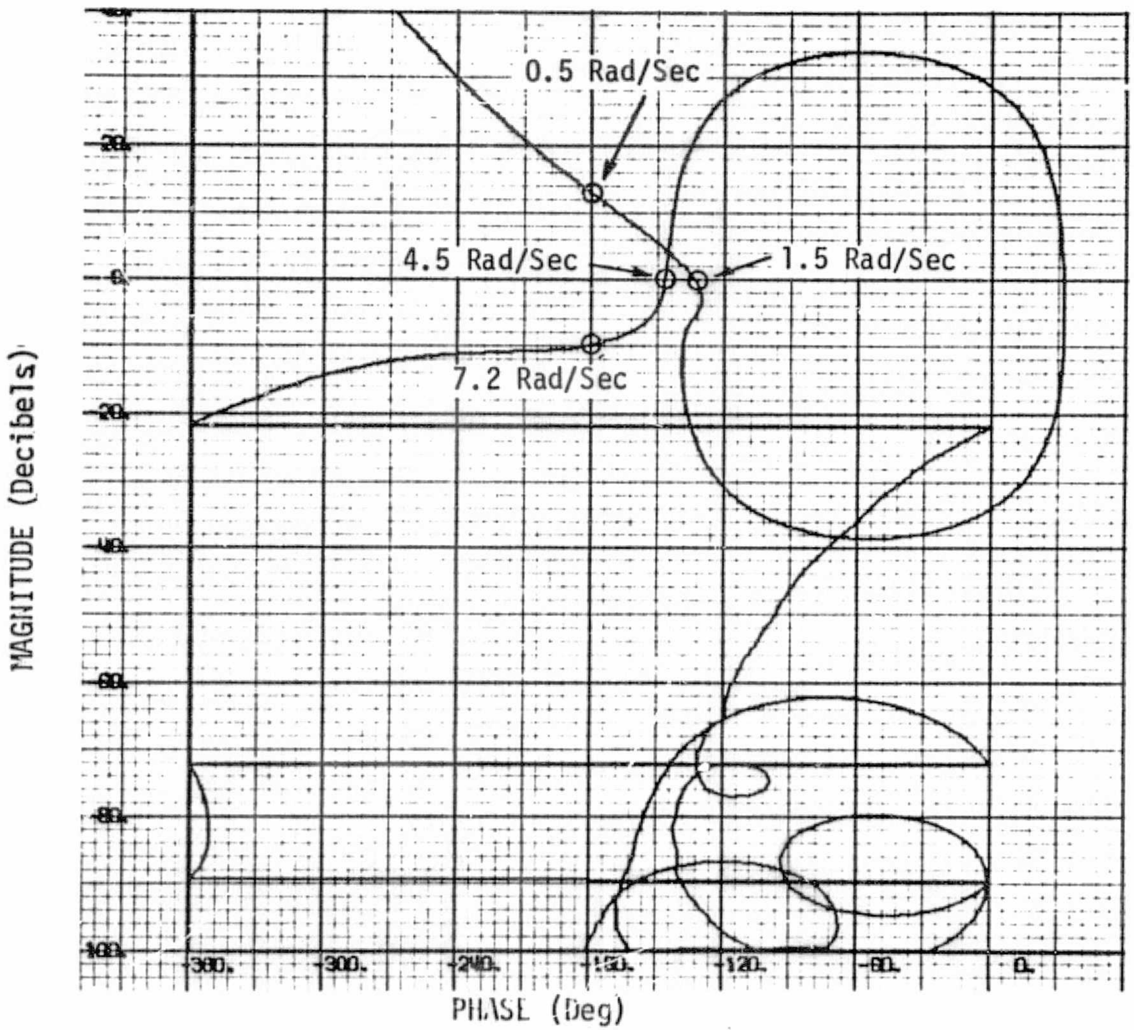


Figure [illegible]-1 Gain versus Phase

4.3 TIME DOMAIN ANALYSES

The orbital initializations for all the TVC cases were identical to the RCS cases. The differences between the various TVC cases were limited to changes in velocity-to-be-gained and in mass properties. Various velocity-to-be-gained values were chosen to exercise the short burn logic in which no guidance steering commands were utilized and the longer burns which incorporated the guidance steering commands. The two vehicle configurations that were tested corresponded to the CSM/DM just prior to circularization and the CSM/DM prior to docking.

Results for TVC Case 1

The objective of this run was to demonstrate the ability of the TVC DAP to control the CSM/DM configuration during a SPS burn. The CSM-alone DAP configuration was selected, the velocity-to-be-gained was 30 fps and the heavy mass properties were selected (see Appendix A for a description of the mass properties).

The TVC DAP satisfactorily controlled the CSM/DM configuration during the SPS burn. The total burn duration was 3.55 seconds. No roll jet firings occurred because of the short burn duration and the small roll axis disturbance. A summary of peak values of some of the major variables for this case is contained in Table 1T-1.

The simulation was initialized with zero angular rates about each of the spacecraft axes and the CDU angles were:

CDUX = 0. deg
CDUY = 0.85 deg
CDUZ = 0.24 deg

At a simulation time of 3.07 seconds the gimbal actuator drive signals were enabled. The gimbals were driven to the positions prescribed by the erasable quantities PACTOFF and YACTOFF which were 1.3 and -0.7 deg, respectively. A four-jet ullage was commanded at a simulation time of 4.07 sec. Jets 2 and 5 turned on and off to provide attitude control during the ullage. The SPS engine was turned on at a simulation time of 12.0 sec and ullage was turned off at 14.01 seconds. The time histories of the CDU angles presented in Figure 1T-1 indicate that the attitude excursions caused by the ignition

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transients were small. The plots of the SPS gimbal angles are shown in Figure 1T-2. The transients caused by the engine startup are quickly damped and no instabilities due to slosh or bending appear in the TVC control loop. The pitch and yaw body-attitude errors are presented in Figure 1T-3 and indicate that, for this short duration burn, the attitude errors at engine cutoff were approximately 0.2 degree. The variables plotted in this figure are PERRB and YERRB which are computed in the TVC DAP and are displayed on the FDAI needles and are updated every 1/2 second by the TVCEXECUTIVE. The roll axis attitude error is shown in Figure 1T-4. No roll axis firings were required because the roll attitude did not exceed the 5 degree deadband.

The SPS engine was turned off at a simulation time of 15.55 seconds and the gimbal drive actuator signals were terminated at 18.06. Following the SPS engine shutdown, there is a 2.5-second delay while the TVC DAP continues to function as the thrust level decays. Plots of the cross-axis velocities are shown in Figure 1T-5. The residual ΔV's were within the expected range of values for a burn of this duration.

Plots of the pitch and yaw axes bending moments at the SM/CM and CM/DM interfaces are presented in Figures 1T-6 through 1T-9. As expected the peak values of the bending moments occurred during the SPS engine startup period. The total bending moment is made up of two parts, the rigid body contribution and the flexible body contribution. The flexible body component is substantial at the SPS engine startup but is quickly damped. Thereafter the bending moment is comprised almost entirely of the rigid body contribution. Torsional loads were not simulated in the TVC cases. The peak values of the loads are not excessive and should present no problems.

Table 1T-1 Summary of Results
TVC Case 1

Maximum TVC Engine Angular Deflection		
Pitch	1.8 Deg	
Yaw	-1.2 Deg	
Maximum Attitude Errors		
Pitch	.5375 Deg	
Yaw	-.46 Deg	
Maximum Generalized Bending Deflections		
Mode 1	-.15E-3 Meters	
Mode 2	.197E-4 Meters	
Mode 3	.0448E-3 Meters	
Mode 4	-.067E-3 Meters	
Mode 5	-.13E-4 Meters	
Mode 6	-.33E-4 Meters	
Maximum Slosh Displacement		
Oxydizer	Y	-.019 Meters
	Z	-.03 Meters
Fuel	Y	-.019 Meters
	Z	-.03 Meters
Maximum Cross Axis ΔV Magnitude		
Z	.382	feet/sec
Y	.58	feet/sec
Maximum Axial Load		
Station 1010	328.8E2 Newtons	
Station 1109.5	140.26E2 Newtons	
Maximum Bending Moment at Station 1010		
Pitch	-46E2 Newton Meters	
Yaw	-220E1 Newton Meters	

Table 1T-1 Summary of Results (Continued)
TVC Case 1

Maximum Bending Moment at Station 1109.5		
Pitch	101.8E1	Newton Meters
Yaw	230	Newton Meters

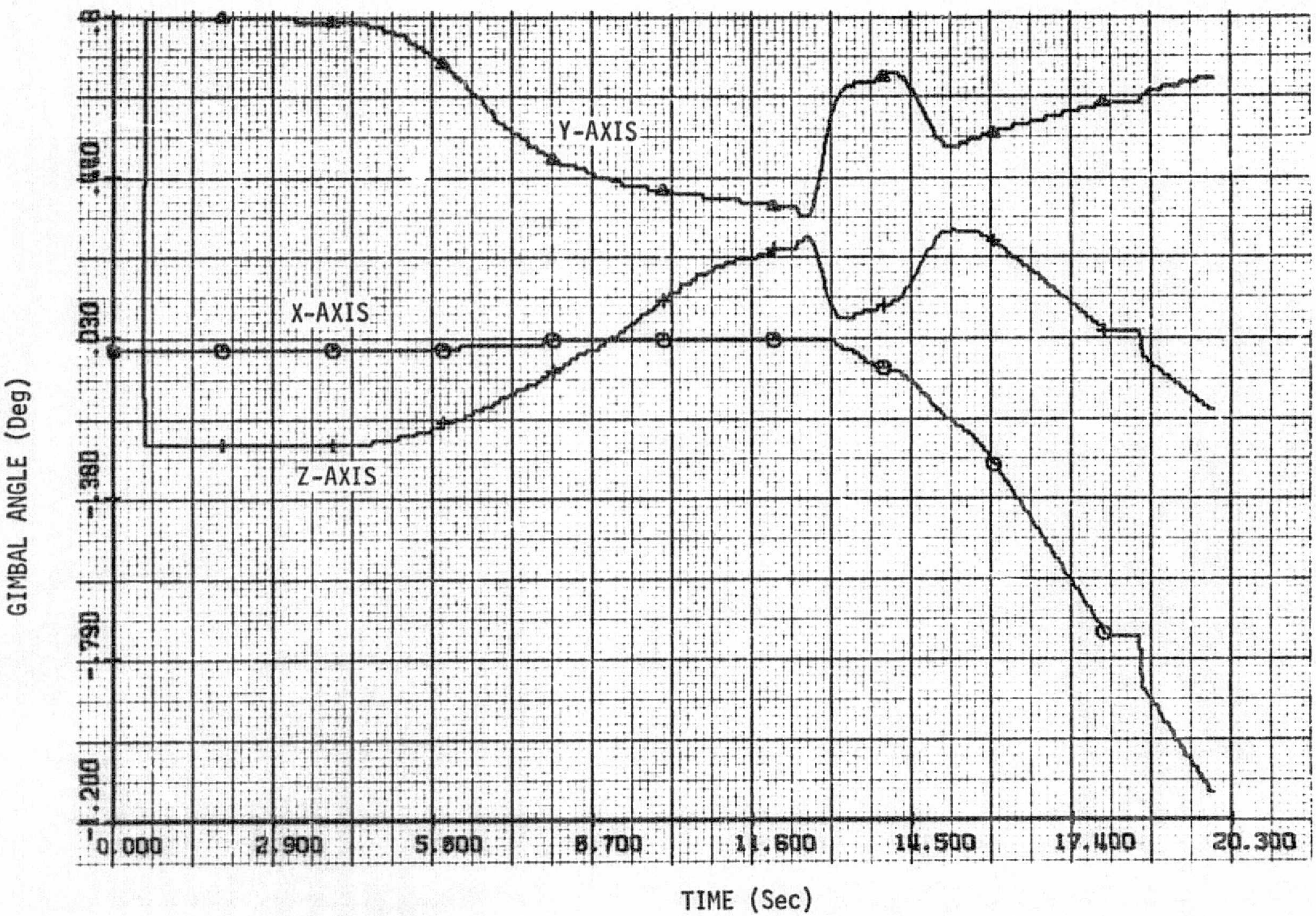

Figure 1T-1 Gimbal Angles Versus Time Case 1

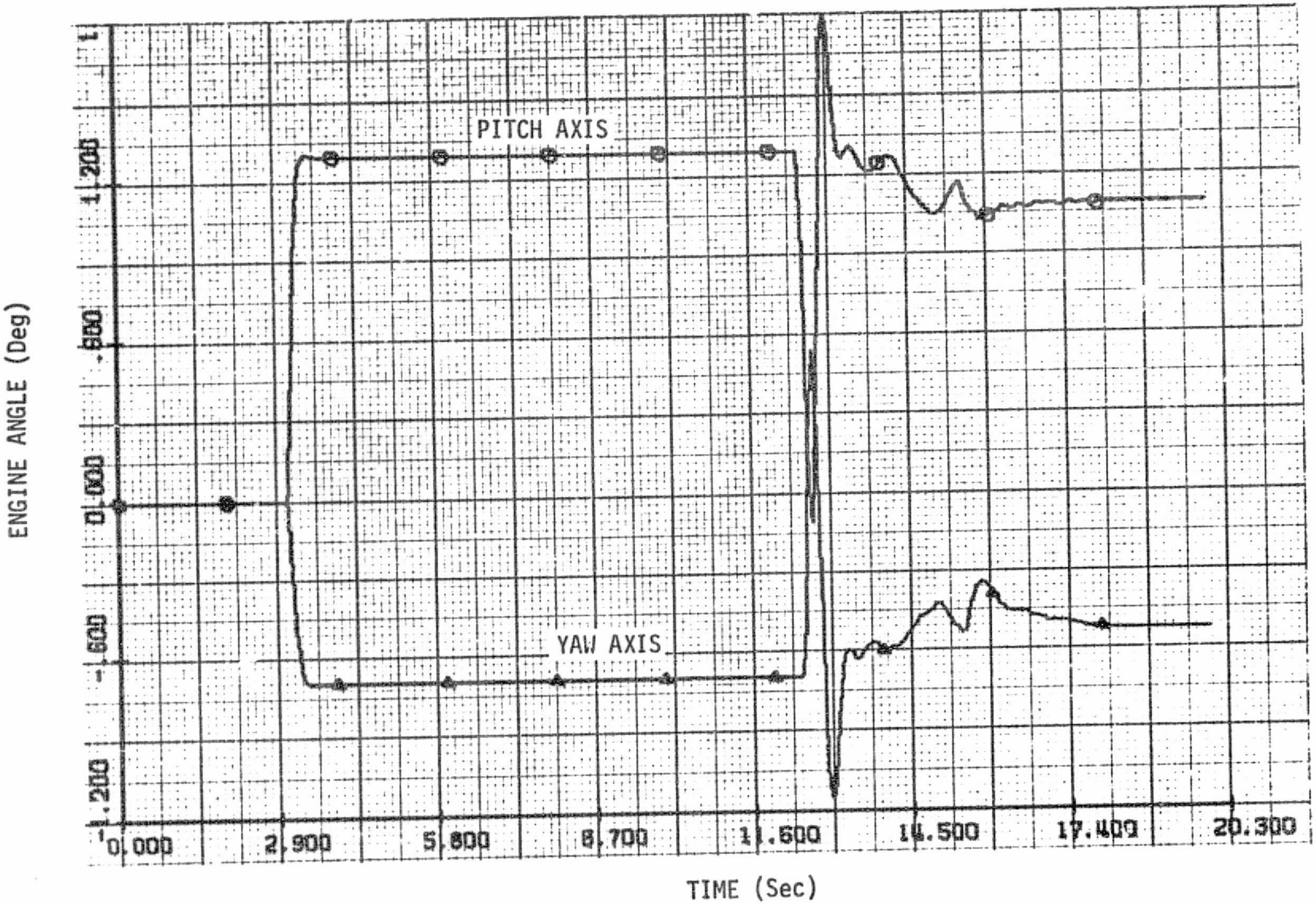

Figure 1T-2 SPS Engine Angle Versus Time Case 1

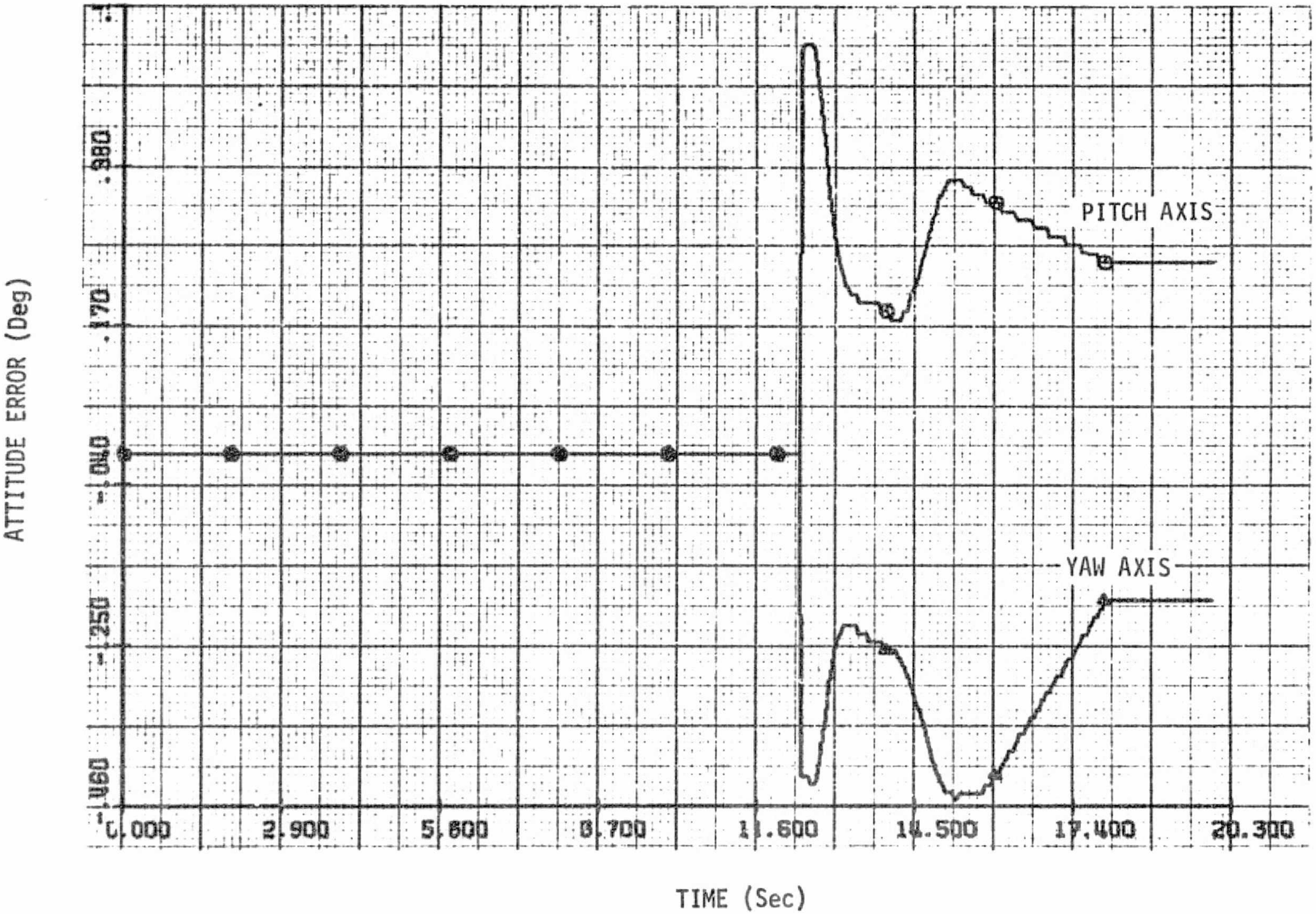

Figure 1T-3 Body Attitude Errors Versus Time Case 1

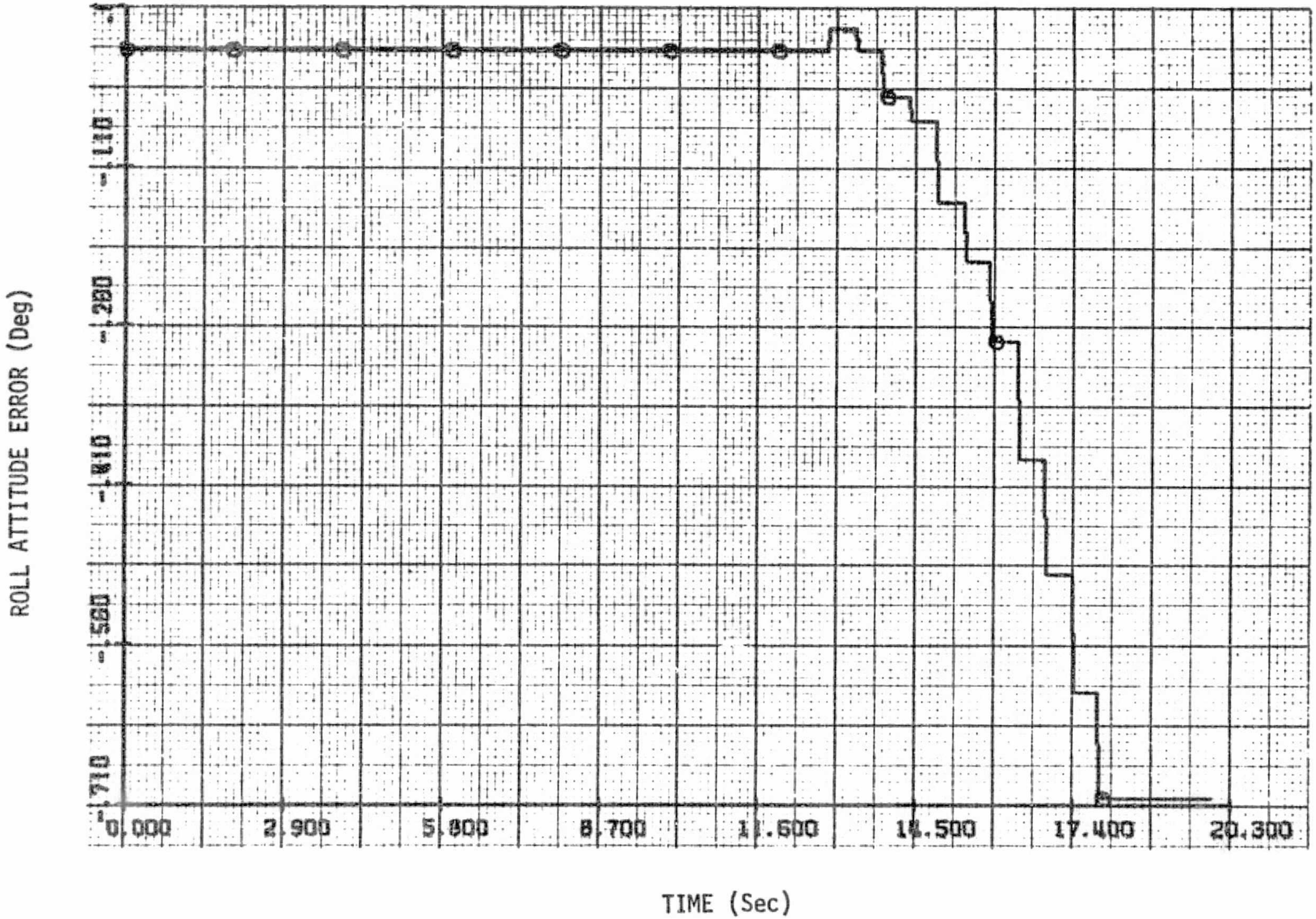

Figure 1T-4 Roll Attitude Error Versus Time Case 1

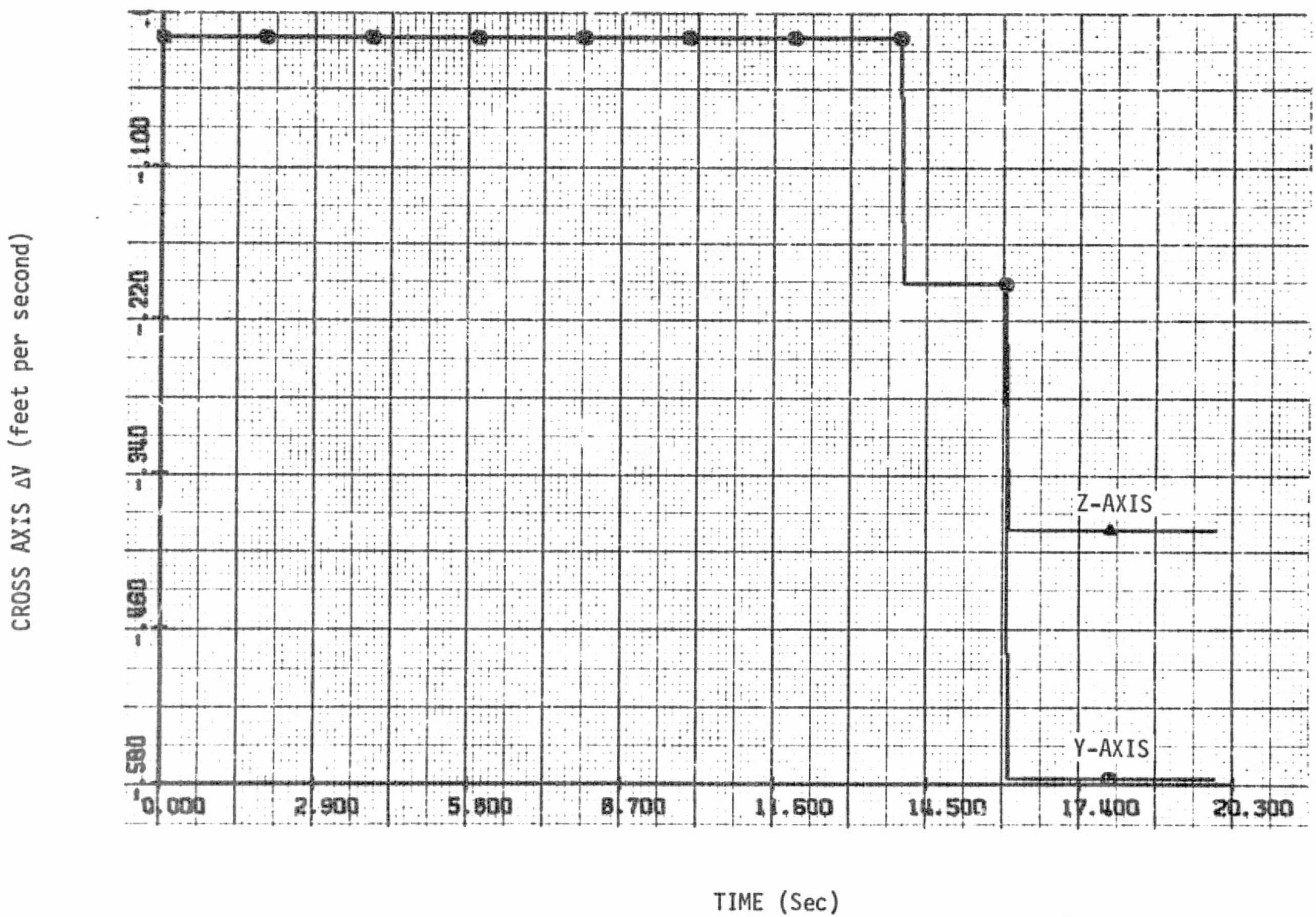

Figure 1T-5 Cross Axis ΔV Versus Time Case 1

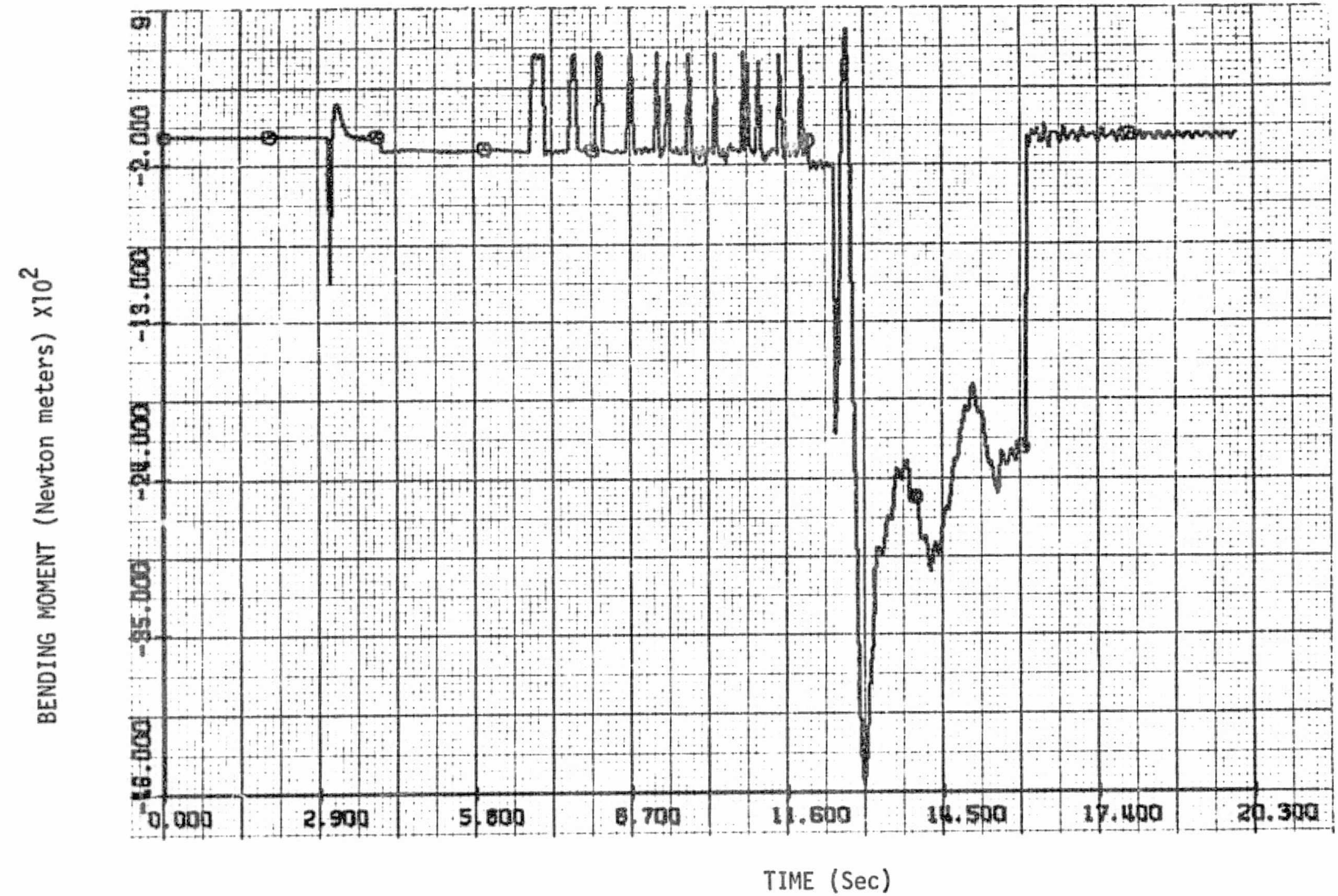

Figure 1T-6   Pitch Axis Bending Moment at Station 1010 Versus Time Case 1

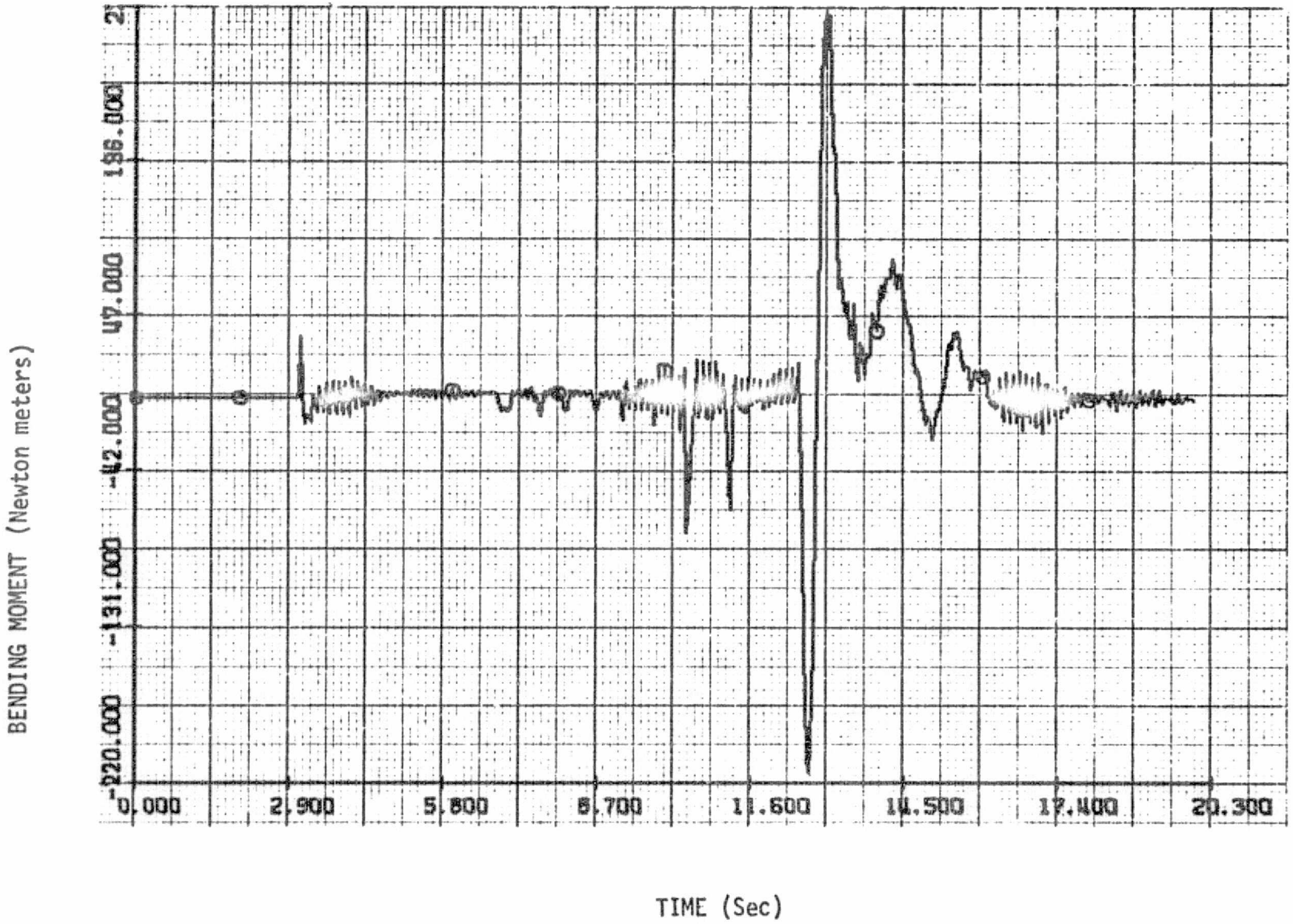

Figure 1T-7   Yaw Axis Bending Moment at Station 1010 Versus Time Case 1

Figure 1T-8   Pitch Axis Bending Moment at Station 1109.5 Versus Time Case 1

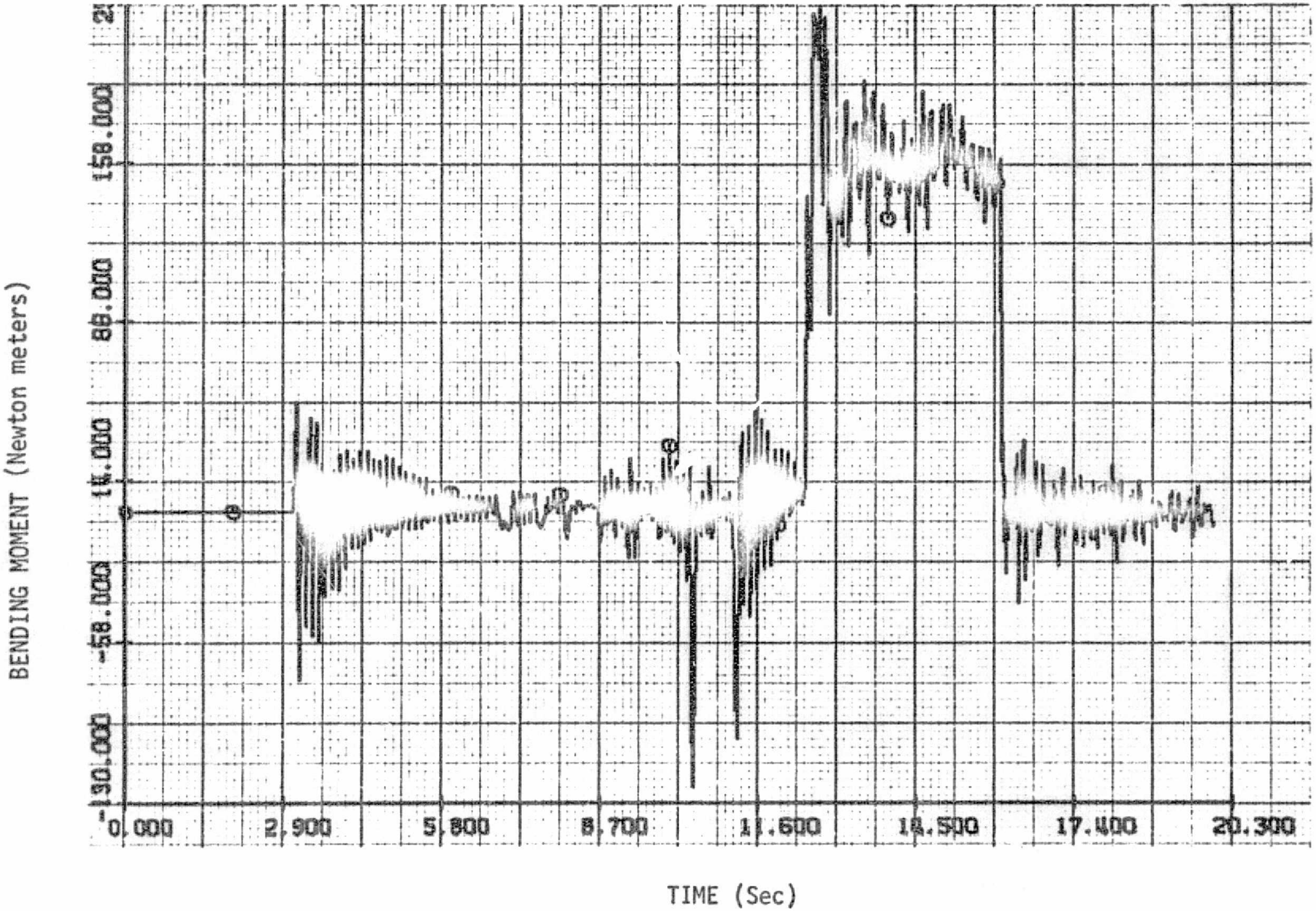

Figure 1T-9 Yaw Axis Bending Moment at Station 1109.5 Versus Time Case 1

Results for TVC Case 2

The objective of this run was to demonstrate the ability of the TVC DAP to control the CSM/DM configuration during a SPS burn. The CSM-alone DAP configuration was selected, the velocity-to-be-gained was 100 fps and the heavy mass properties were selected (see Appendix A for mass properties).

The TVC DAP satisfactorily controlled the CSM/DM configuration during the SPS burn. The total burn duration was 12.78 seconds. A summary of peak values of some of the major variables for this case is contained in Table 2T-1. Time histories of pertinent variables are presented in Figures 2T-1 through 2T-9.

The timeline of major events for this case is as follows:

Event	Simulation Time (sec)
SPS actuator signals enabled	3.07
Ullage on	4.07
SPS engine on	12.00
Ullage off	14.01
SPS off	24.78
Actuator signals off	27.29

The initialization for this case was identical to that of the TVC Case 1. Further, the DAP response for this case was almost identical to Case 1. The time histories of the transients induced by the SPS ignition were the same for both cases. The DAP was able to reduce the attitude errors at engine cutoff (≈ 0.08 degree) because of the longer burn duration as indicated in Figure 2T-3. A review of the printout associated with this case revealed that no guidance steering commands were issued. The TVC DAP was stable and there were no adverse interactions with the slosh and bending.

Plots of the pitch and yaw axes bending moments for the two interfaces are shown in Figures 2T-6 through 2T-9. As with the other variables, the time histories of the bending moments for this case were very similar to the corresponding variables shown in Case 1 for the first three or four seconds of the burn. The peak values of the bending moments occurred during the SPS thrust buildup and were noticeably reduced thereafter.

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At a simulation time of 26.96 seconds, Jets 9 and 11 turned on for 0.184 sec to produce a +X axis roll torque. At 29.56 sec Jets 14 and 16 turned on for 0.040 sec to produce a -X axis torque. These firings excited the third, fourth and fifth bending modes. This excitation caused the noticeable yaw axis bending moments after the termination of the SPS thrust. This effect can be observed in Figures 2T-7 and 2T-9. As with the previous cases, the peak values of the loads were not excessive and no instability problems were observed.

Table 2T-1 Summary of Results
TVC Case 2

Maximum TVC Engine Angular Deflection

Pitch	1.8 Deg
Yaw	- 1.2 Deg

Maximum Attitude Errors

Pitch	.53 Deg
Yaw	-.46 Deg

Maximum Generalized Bending Deflections

Mode 1	-.15E-3 Meters
Mode 2	.196E-4 Meters
Mode 3	-.051E-3 Meters
Mode 4	-.067E-3 Meters
Mode 5	-.25E-4 Meters
Mode 6	-.33E-4 Meters

Maximum Slosh Displacement

Oxydizer	Y	-.019 Meters
	Z	-.03 Meters
Fuel	Y	-.03 Meters
	Z	-.019 Meters

Maximum Cross Axis ΔV Magnitude

Z	.378 feet/sec
Y	1.34 feet/sec

Maximum Axial Load

Station 1010	324.2E2 Newtons
Station 1109.5	140.0E2 Newtons

Table 2T-1 Summary of Results (Con't)
TVC Case 2

Maximum Bending Moment at Station 1010

Pitch	-46.E2	Newton Meters
Yaw	-220.E1	Newton Meters

Maximum Bending Moment at Station 1109.5

Pitch	-100.6E1	Newton Meters
Yaw	-43.E1	Newton Meters

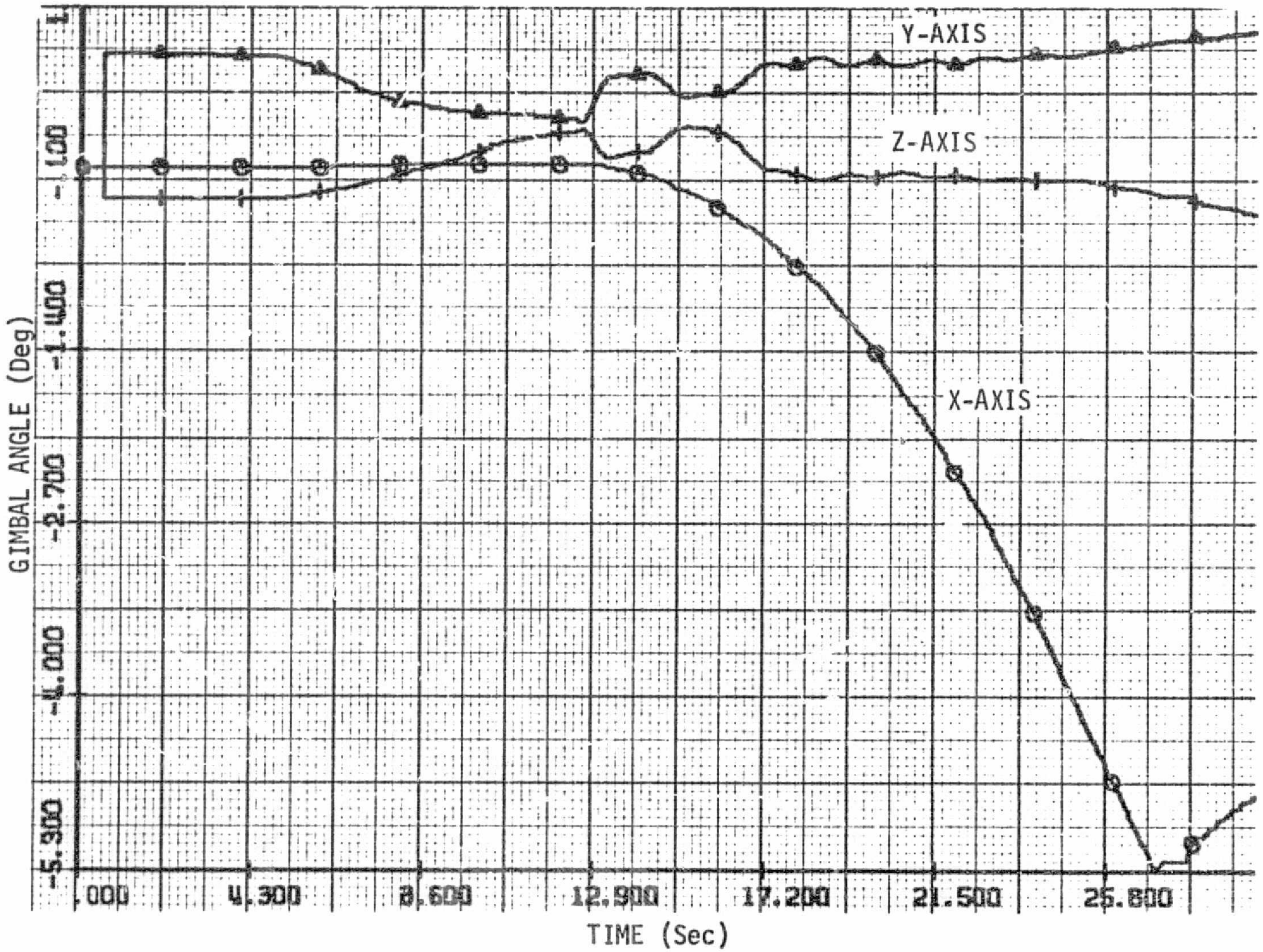

Figure 2T-1 Gimbal Angle Versus Time
Case 2

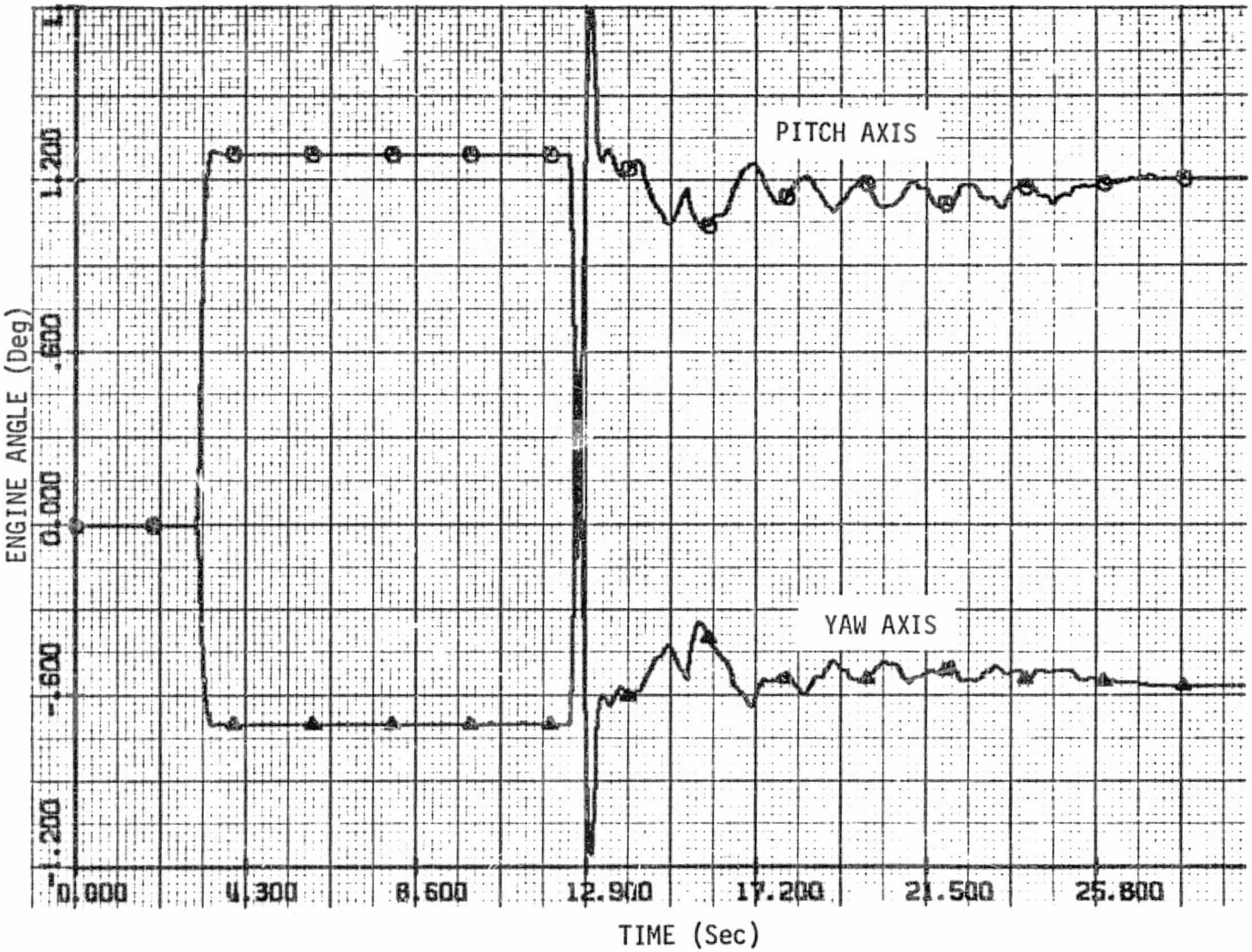

Figure 2T-2 SPS Engine Angle Versus Time
Case 2

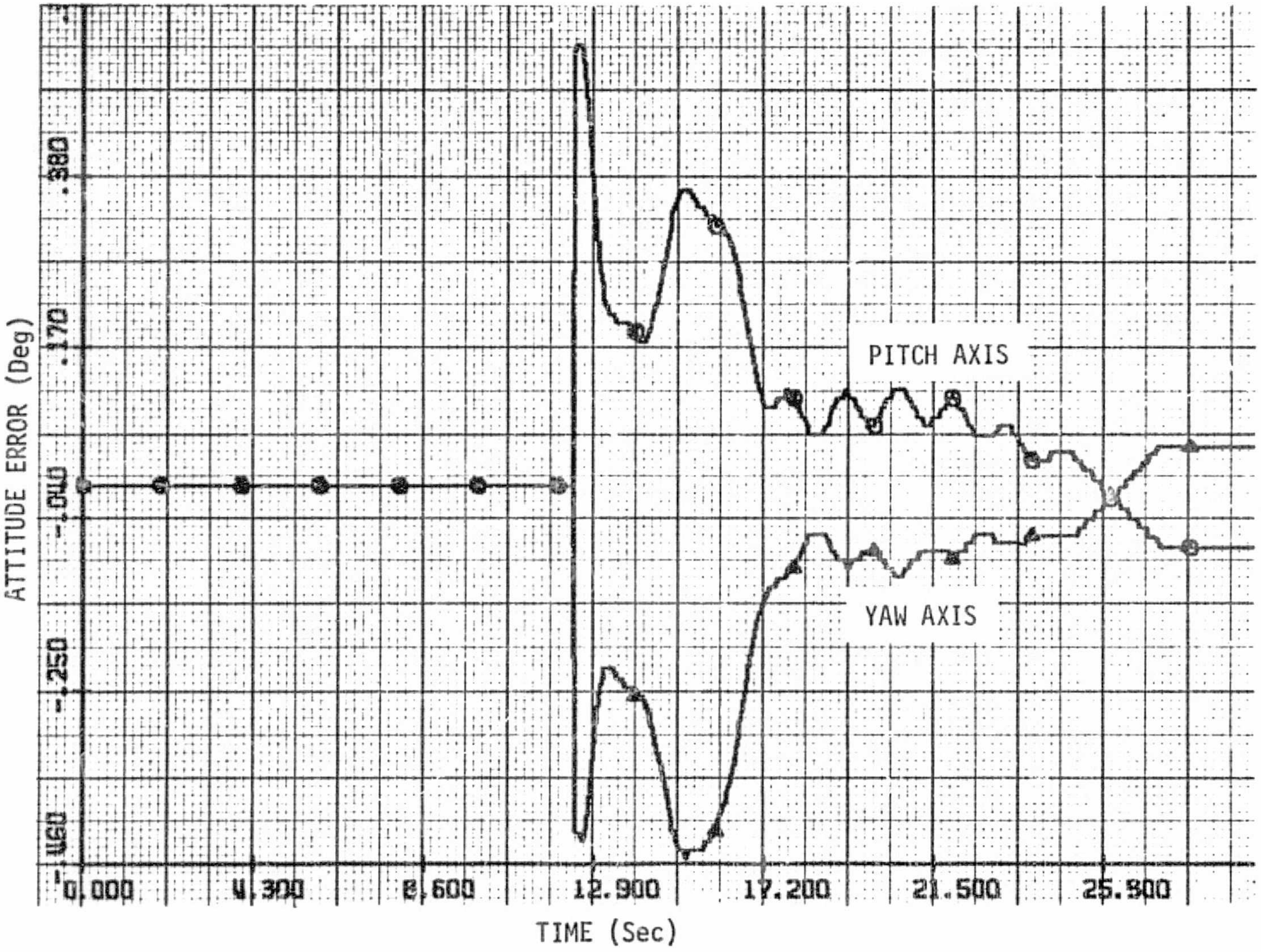

Figure 2T-3 Body Attitude Error Versus Time
Case 2

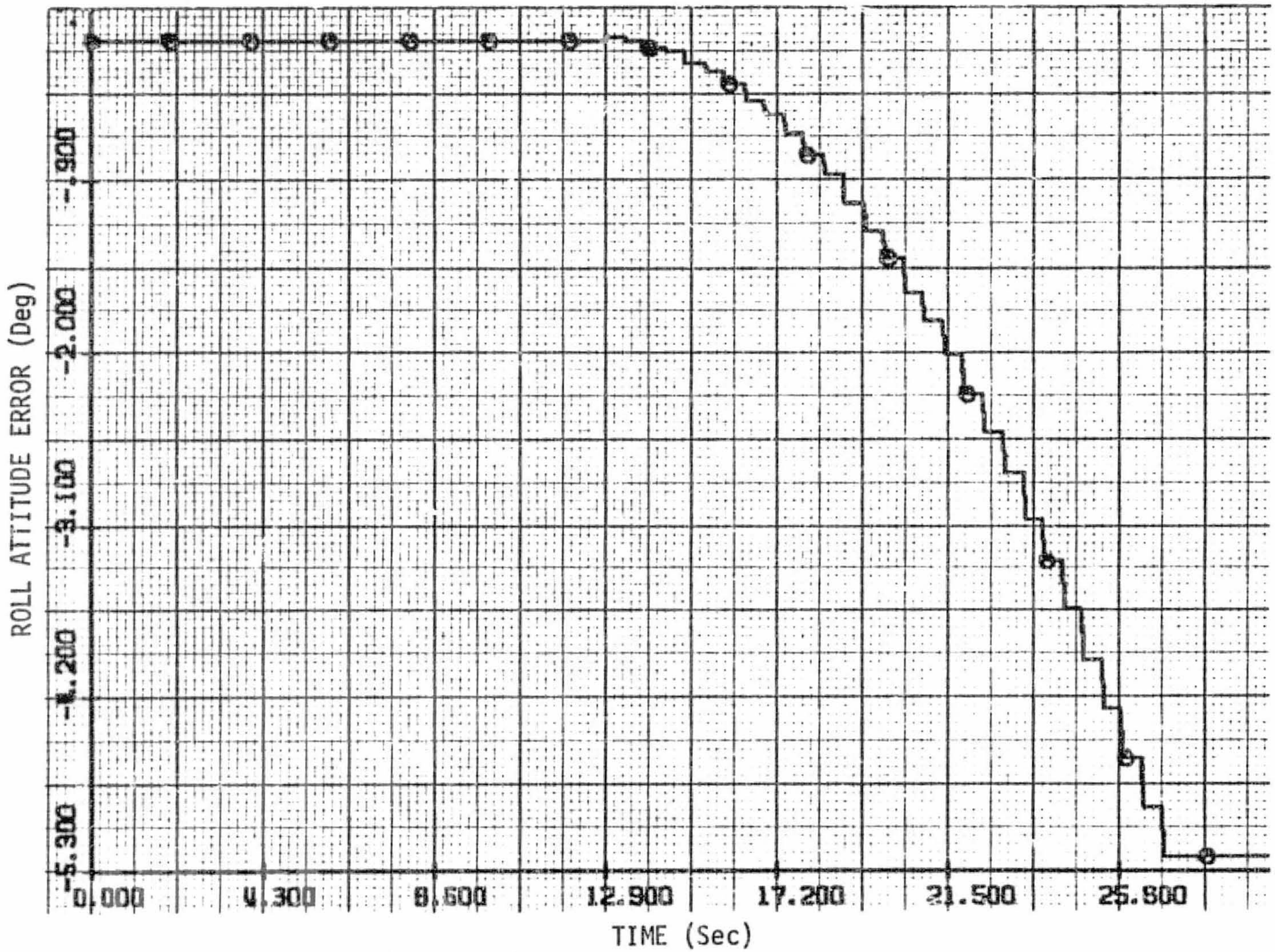

Figure 2T-4 Roll Attitude Error Versus Time
Case 2

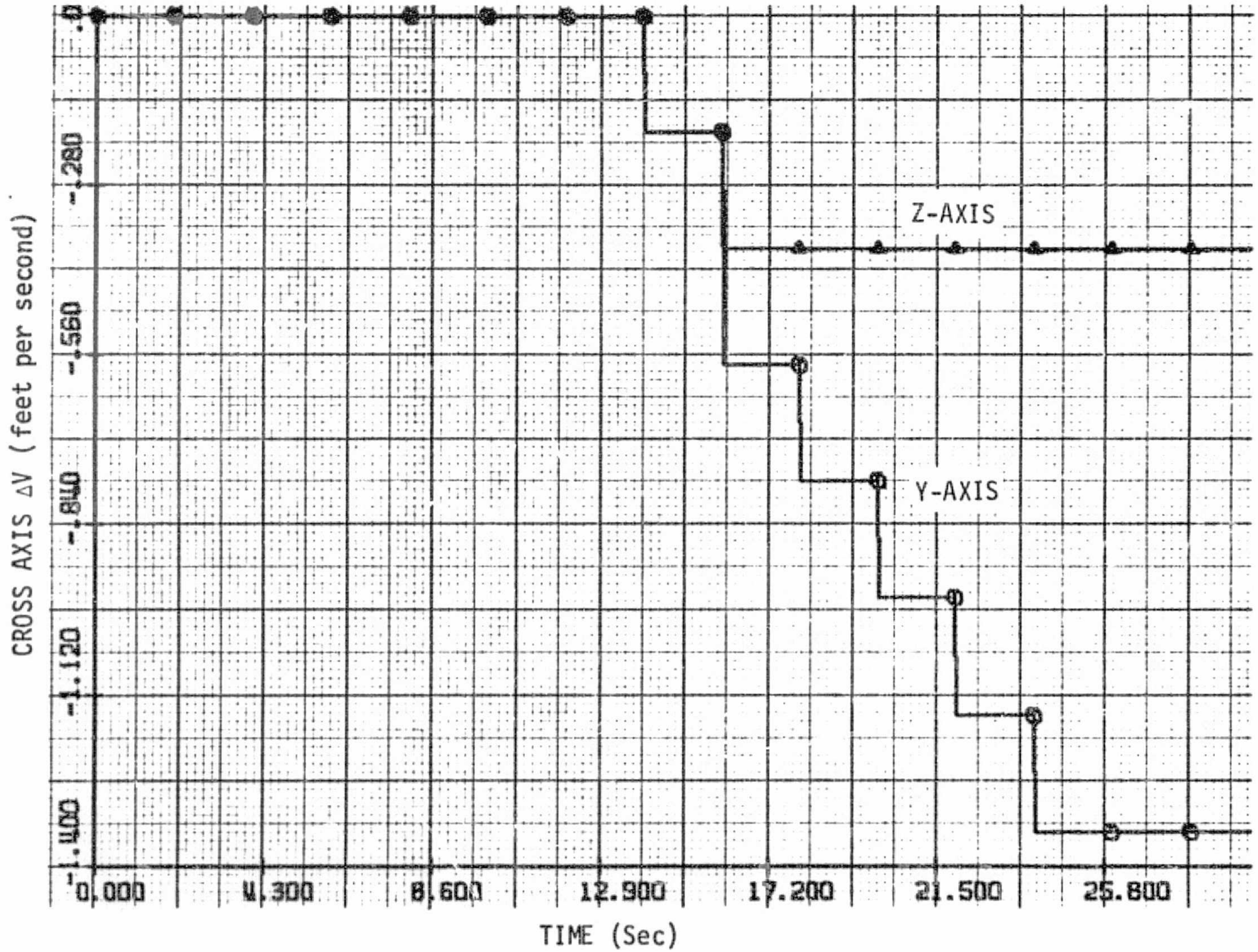

Figure 2T-5 Cross Axis ΔV Versus Time
Case 2

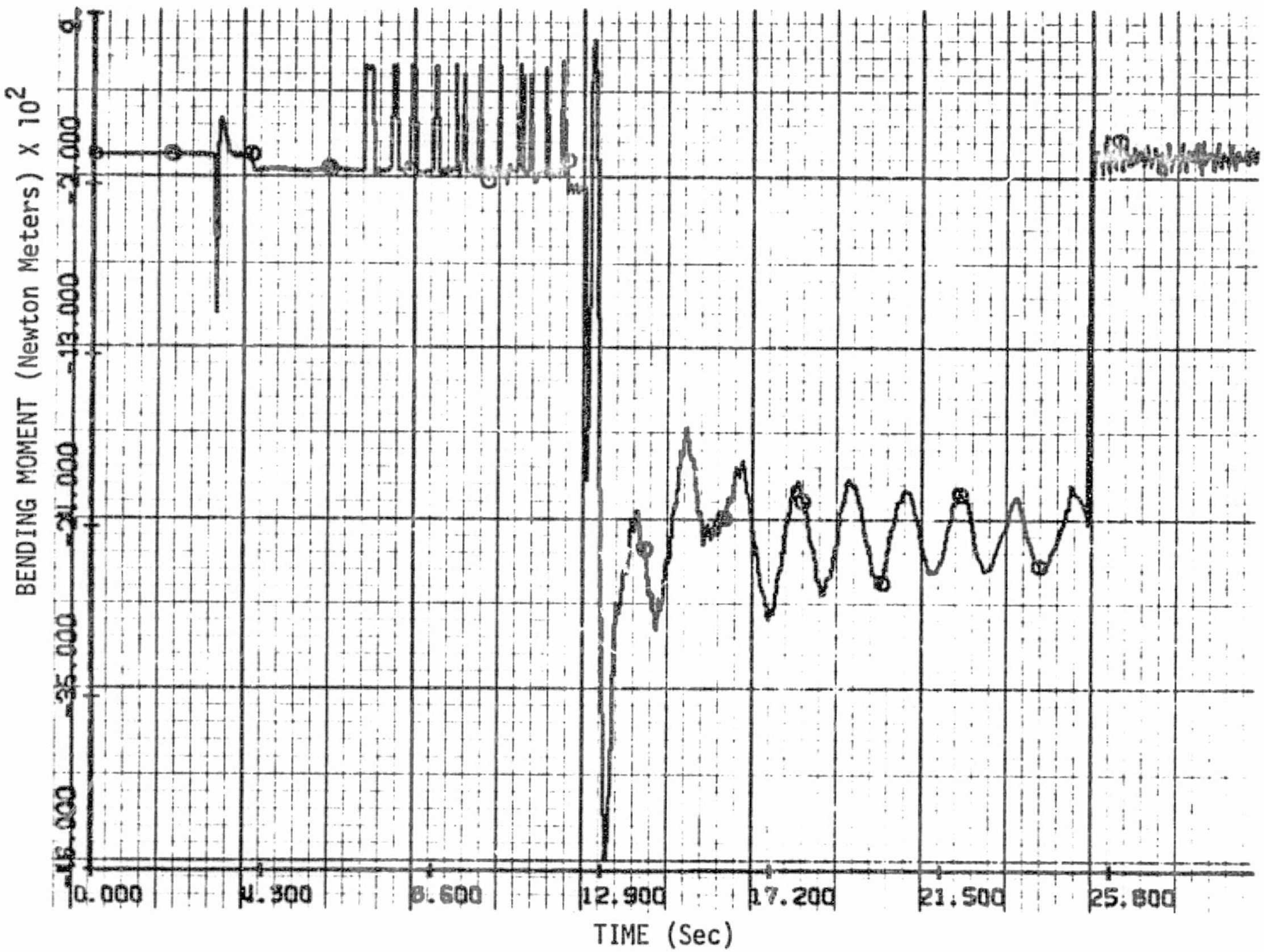

Figure 2T-6   Pitch Axis Bending Moment at Station 1010 versus Time
Case 2

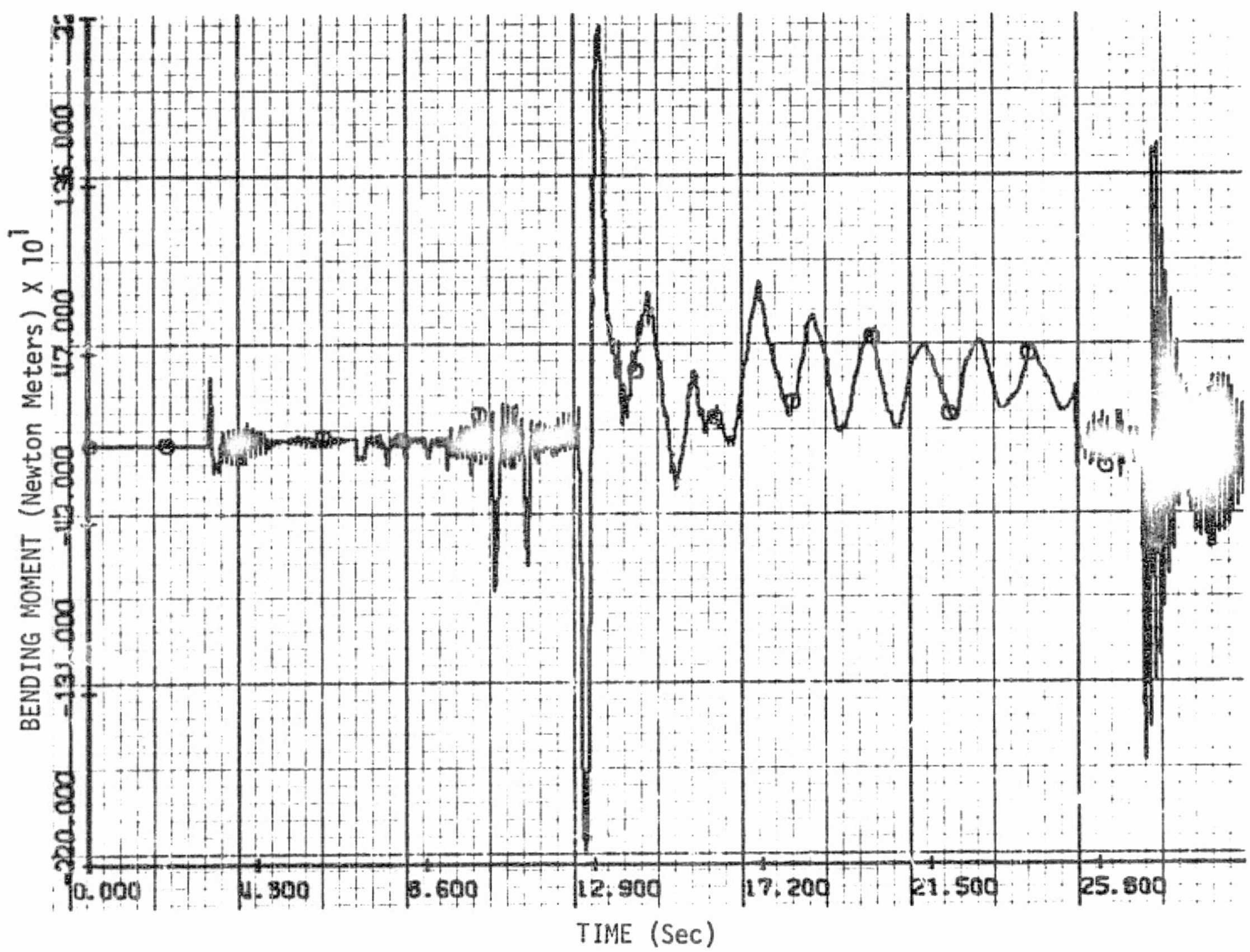

Figure 2T-7 Yaw Axis Bending Moment at Station 1010 Versus Time Case 2

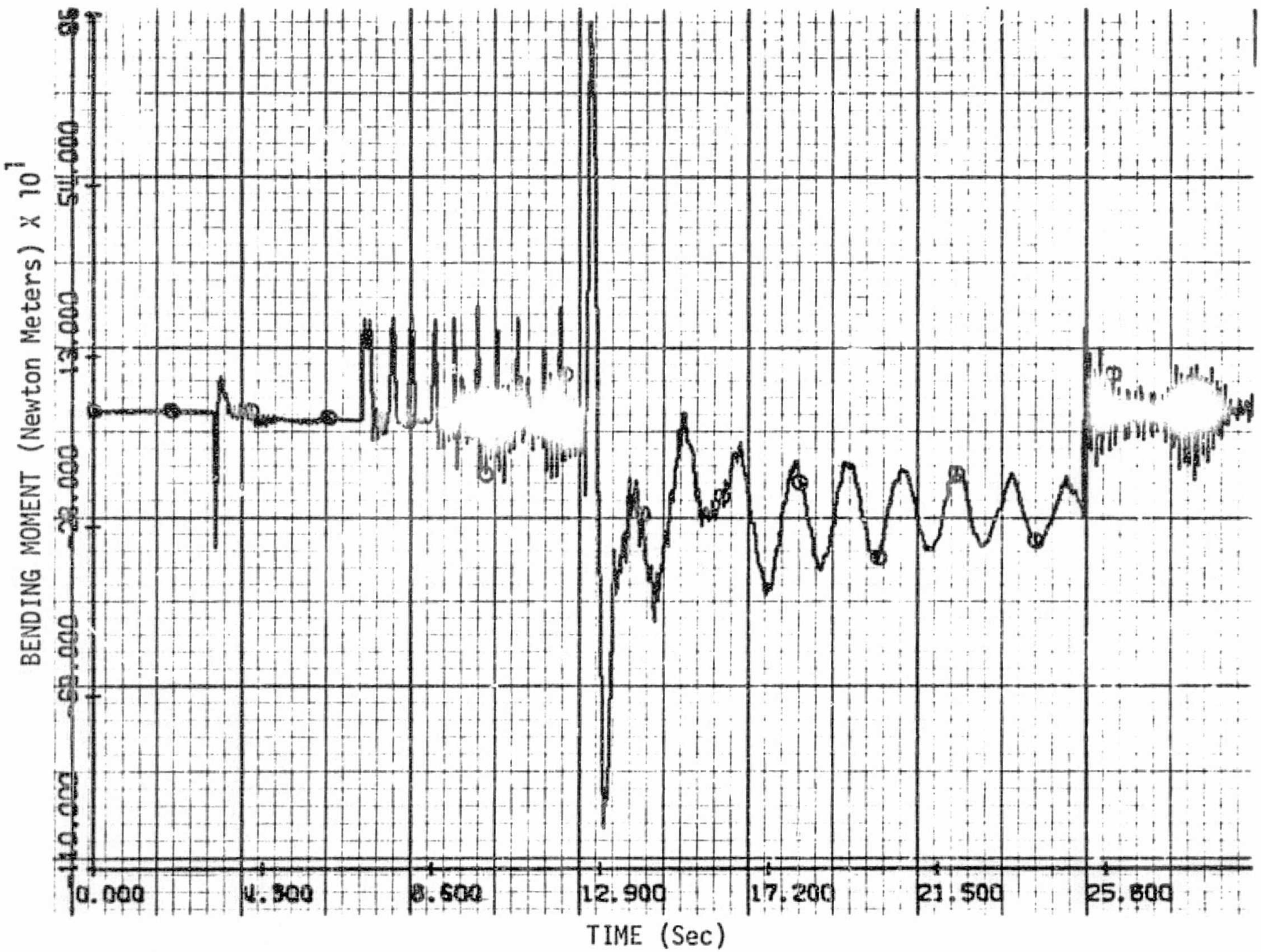

Figure 2T-8 Pitch Axis Bending Moment at Station 1109.5 Versus Time
Case 2

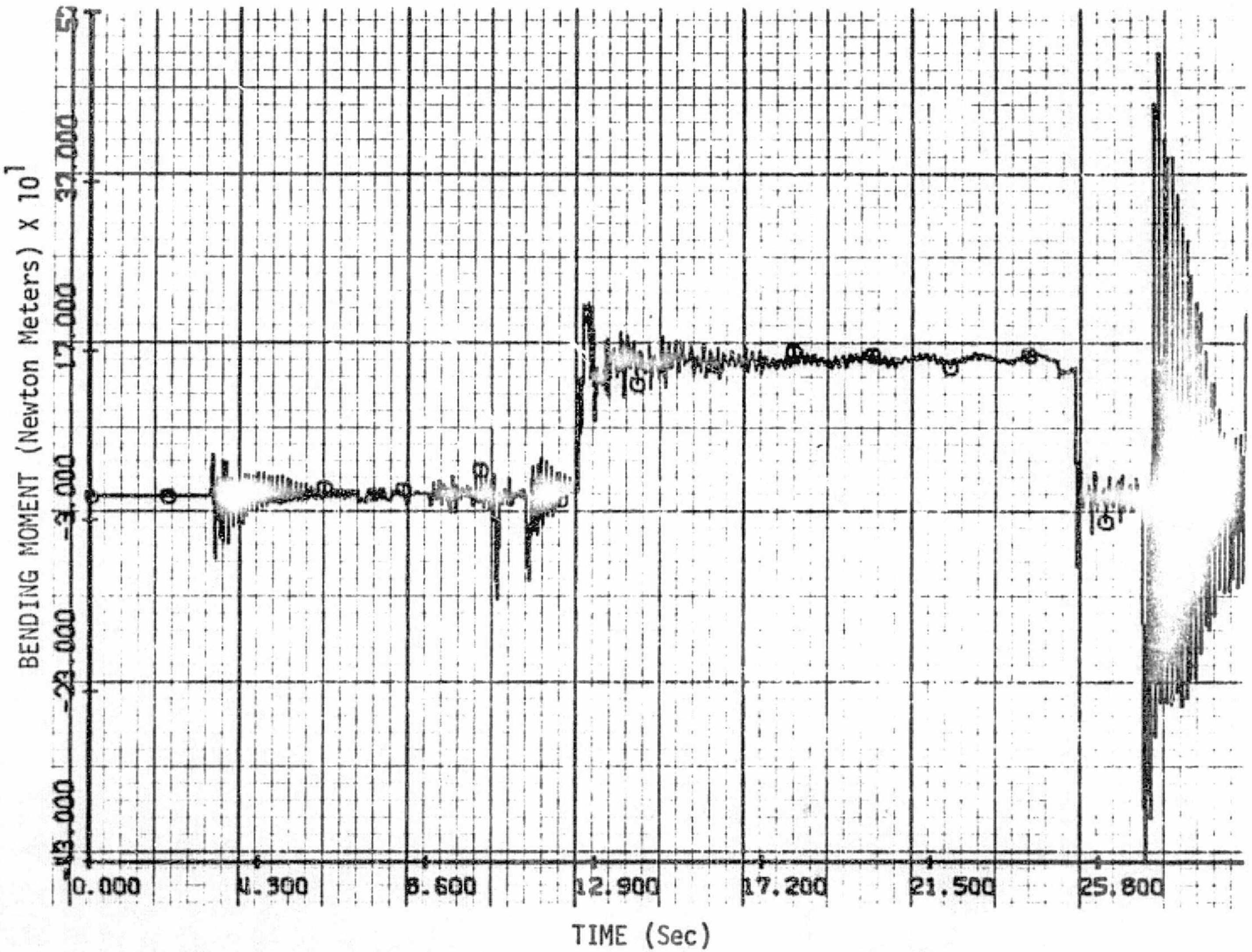

Figure 2T-9 Yaw Axis Bending Moment at Station 1109.5 Versus Time Case 2

Results for TVC Case 3

The objective of this run was to demonstrate the ability of the TVC DAP to control the CSM/DM configuration during a SPS burn. The CSM-alone DAP configuration was selected, the velocity-to-be-gained was 500 fps and the heavy mass properties were selected (see Appendix A for mass properties).

The TVC DAP satisfactorily controlled the CSM/DM configuration during the SPS burn. The total burn duration was 23.2 seconds. A summary of peak values of some of the major variables for this case is contained in Table 3T-1. Time histories of pertinent variables are presented in Figures 3T-1 through 3T-11.

The timeline of major events for this case is as follows:

Event	Simulation Time (sec)
SPS actuator signals enabled	3.07
Ullage on	4.07
SPS engine on	12.00
Ullage off	14.01
SPS off	34.71
Actuator signals off	37.22

The initialization and sequence for this case was identical to TVC Cases 1 and 2 with the exception that the velocity-to-be-gained was 500 fps. The time histories of the transients induced by the SPS ignition were the same as in the previous two cases. At a simulation time of 15 sec the guidance steering loop issued the first steering command. Steering commands were issued to compensate for the initial misalignment of the SPS engine and the transients induced at ignition. These commands were present until a time of 32 sec. Time histories of the steering commands are presented in Figures 3T-4 and 3T-5.

Because of the longer burn duration the DAP was able to null the attitude errors and reach a steady-state operation point. The pitch and yaw attitude errors shown in Figure 3T-3 were nulled approximately 17 seconds after ignition and remained close to zero thereafter. The SPS gimbals were essentially trimmed at a simulation time of 20 sec and displayed a very stable operation for the remaining portion of the run. The SPS gimbal angles

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are shown in Figure 3T-2. Disturbances about the vehicle X-axis caused the roll axis to diverge and two roll-axis firings occurred at times of 2.65 and 32.0 sec. These firings of the roll jets were required to keep the roll attitude within the 5 deg attitude deadband. The roll attitude time history is shown in Figure 3T-6. It can be observed from Figure 3T-7 that the magnitude of the cross-axis velocity in the Z axis was approximately the same as the previous case. The Y axis velocity however was only one-half of the previous case because of the presence of the steering commands.

Time histories of the bending moments at the CM/SM and CM/DM interfaces are presented in Figures 3T-8 through 3T-11. These figures show that the loads are insensitive to the duration of the burn and the peak values occurred primarily at the SPS ignition. The loads for this case are essentially the same as Case 2 and are not adversely affected by the increased burn duration.

Table 3T-1 Summary of Results
TVC Case 3

Maximum TVC Engine Angular Deflection

Pitch	1.8	Deg
Yaw	-1.2	Deg

Maximum Attitude Errors

Pitch	.538	Deg
Yaw	-.47	Deg

Maximum Generalized Bending Deflections

Mode 1	-.15E-3	Meters
Mode 2	.194E-4	Meters
Mode 3	.0442E-3	Meters
Mode 4	-.067E-3	Meters
Mode 5	-.03E-3	Meters
Mode 6	-.33E-4	Meters

Maximum Slosh Displacement

Oxydizer	Y	-.019	Meters
	Z	-.03	Meters
Fuel	Y	-.019	Meters
	Z	-.03	Meters

Maximum Cross Axis ΔV Magnitude

Y	.77	feet/sec
Z	.386	feet/sec

Maximum Axial Load

Station 1010	328.8E2	Newtons
Station 1109.5	140.26E2	Newtons

Maximum Bending Moment at Station 1010

Pitch	-46.E2	Newton Meters
Yaw	-220E1	Newton Meters

Table 3T-1 Summary of Results (Continued)
TVC Case 3

Maximum Bending Moment at Station 1109.5

Pitch	-101.8E1	Newton Meters
Yaw	-34E1	Newton Meters

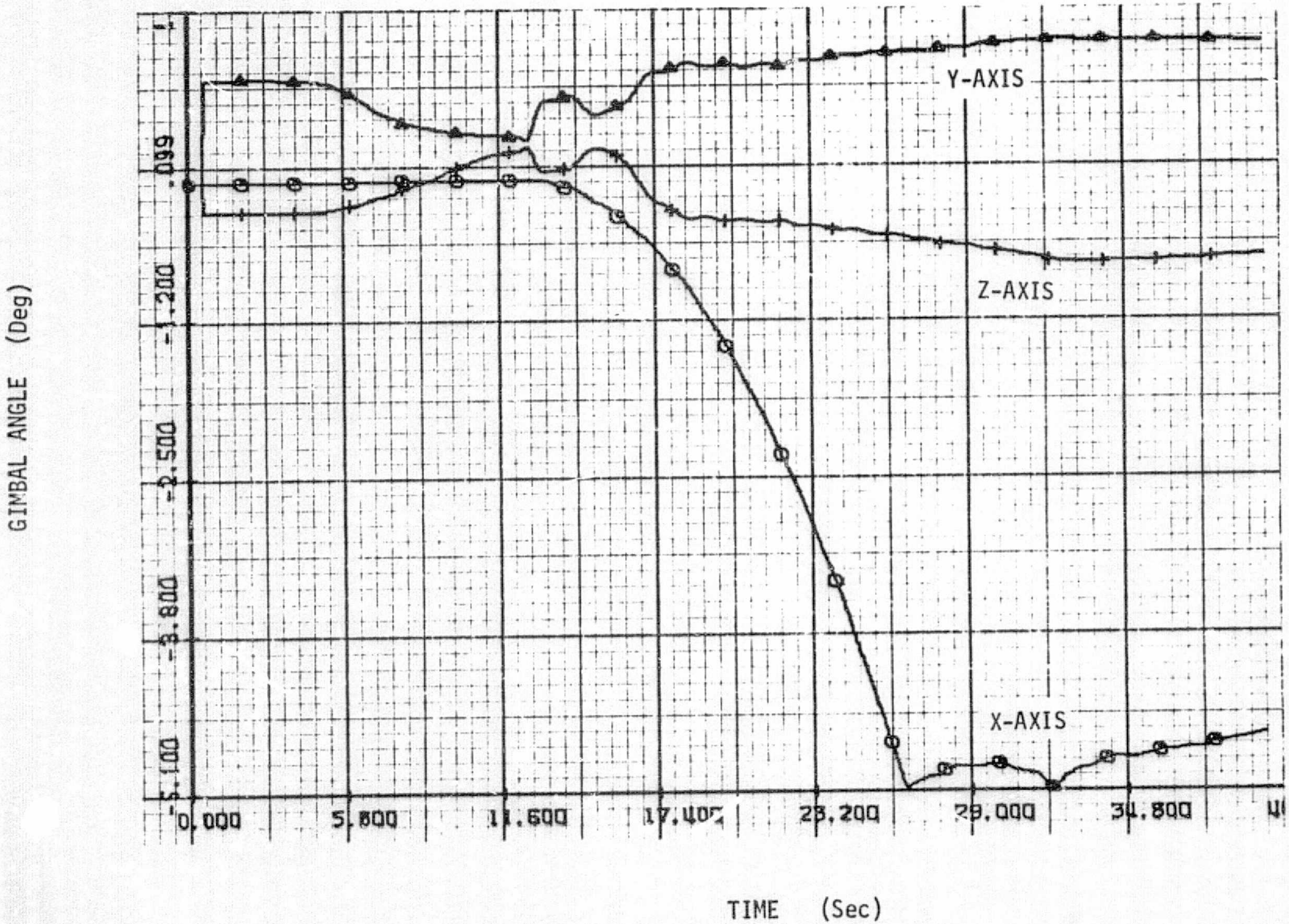

Figure 3T-1 Gimbal Angles Versus Time Case 3

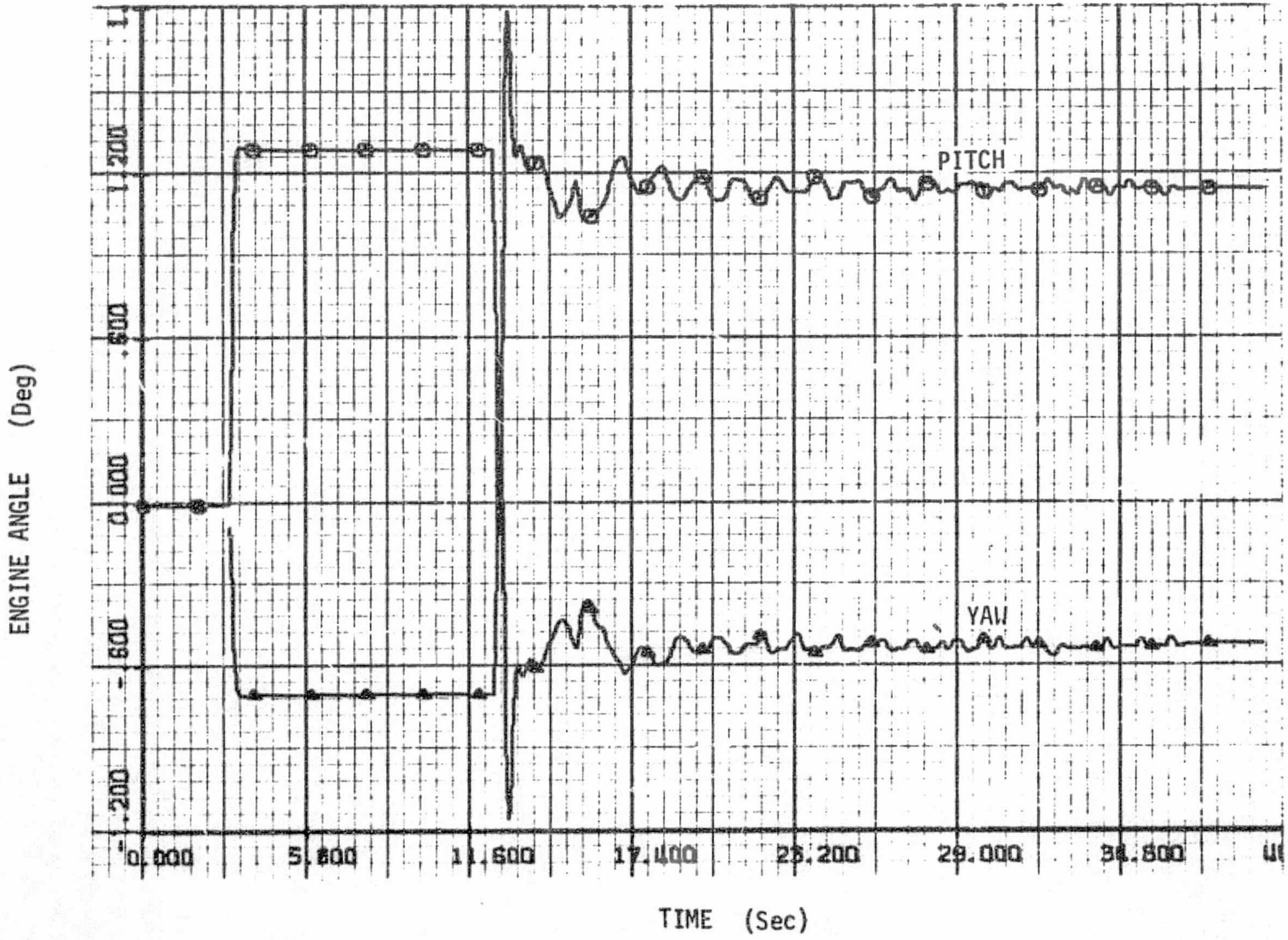

Figure 3T-2 SPS Engine Angle Versus Time Case 3

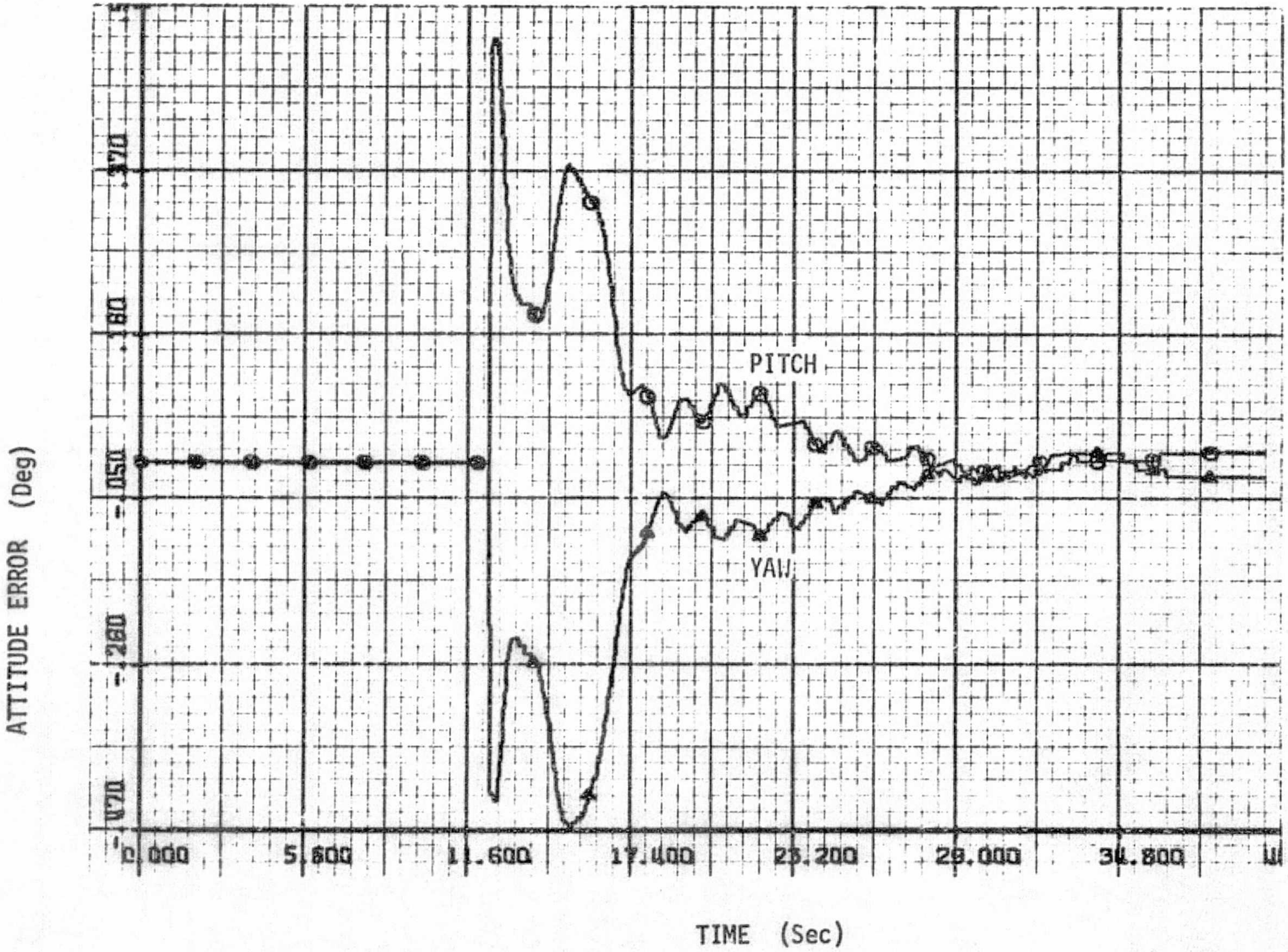

Figure 3T-3 Body Attitude Errors Versus Time Case 3

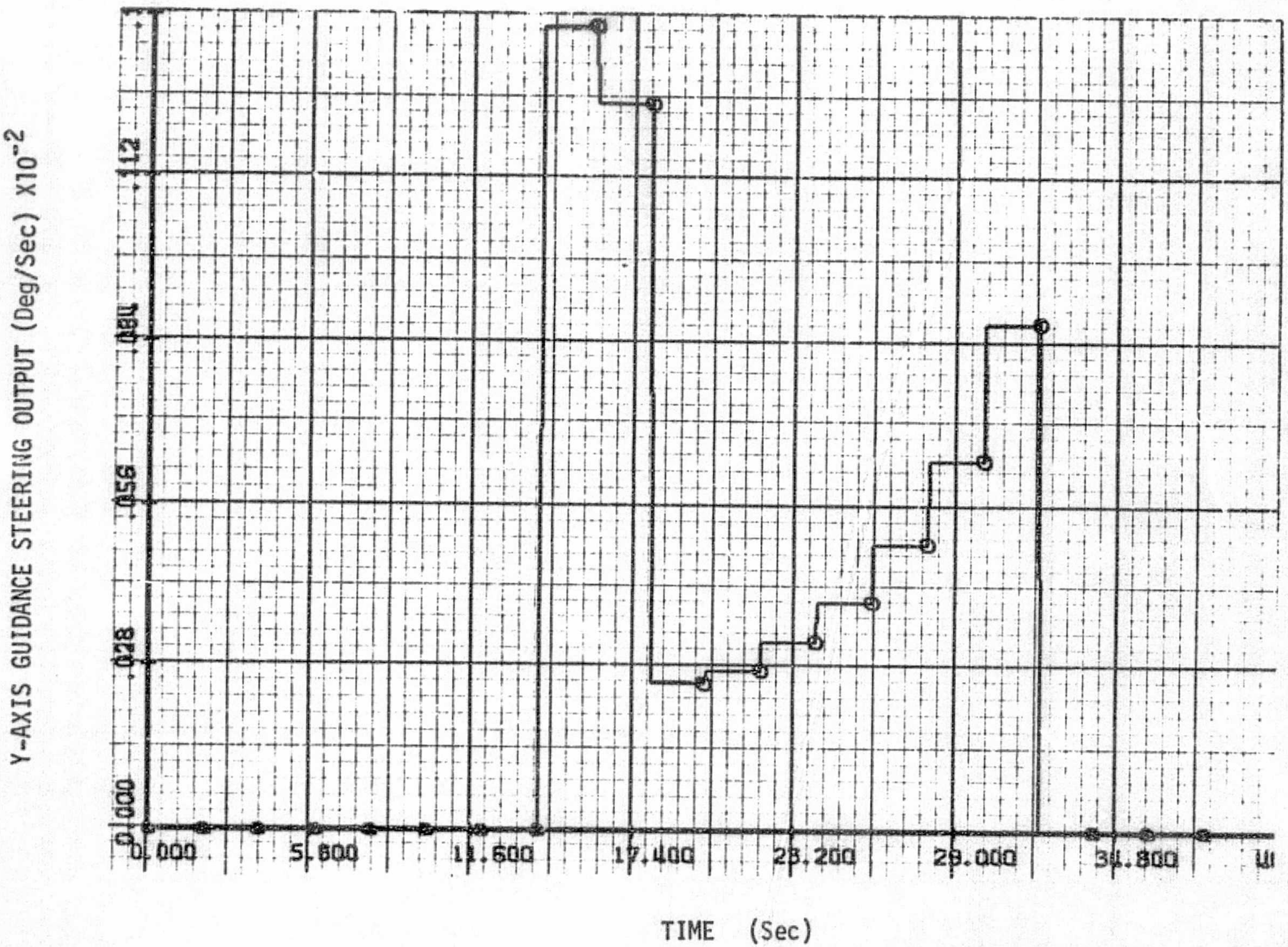

Figure 3T-4 Y - Axis Guidance Steering Output Versus Time Case 3

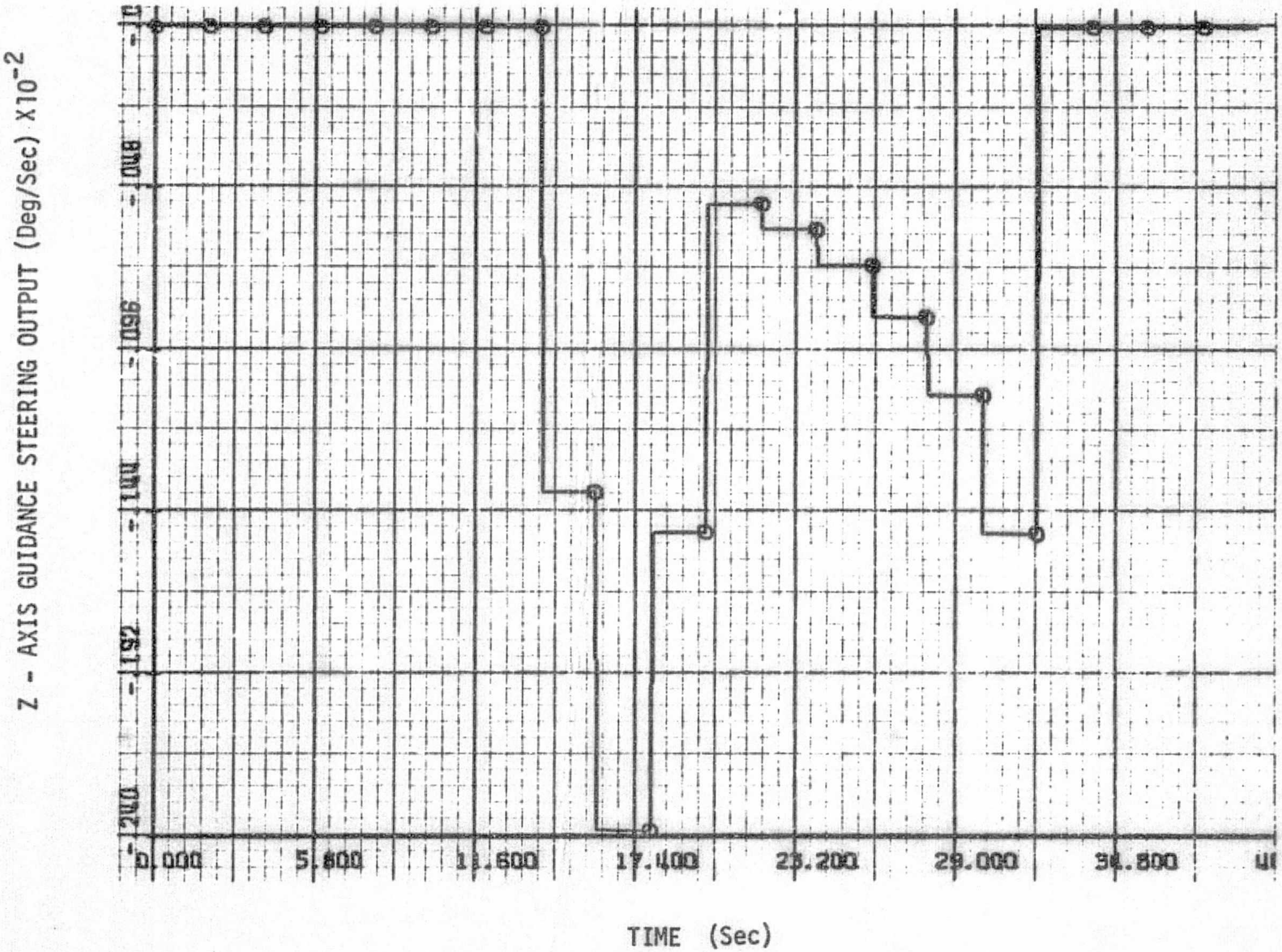

Figure 3T-5 Z - Axis Guidance Steering Output Versus Time Case 3

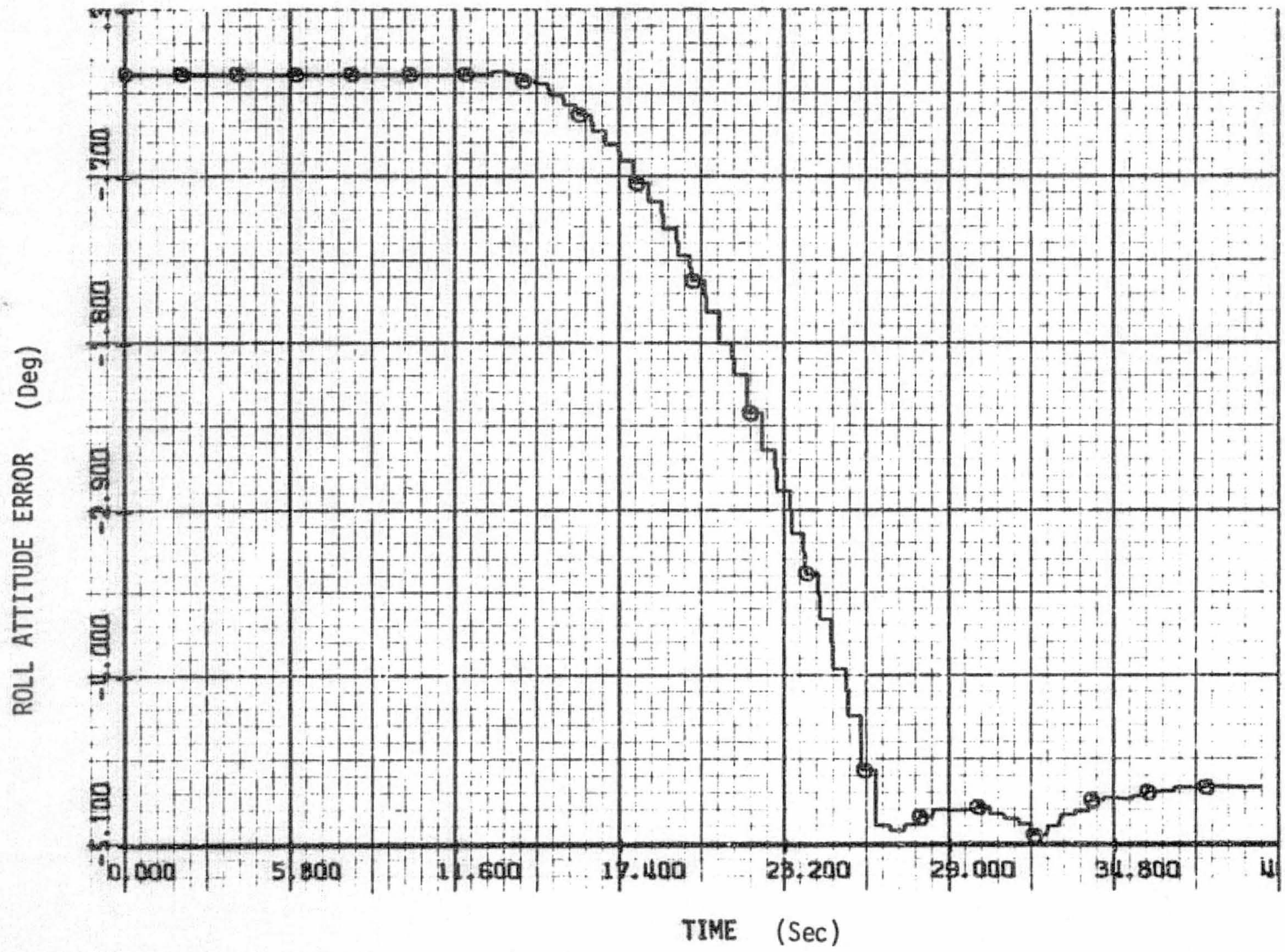

Figure 3T-6 Roll Attitude Error Versus Time Case 3

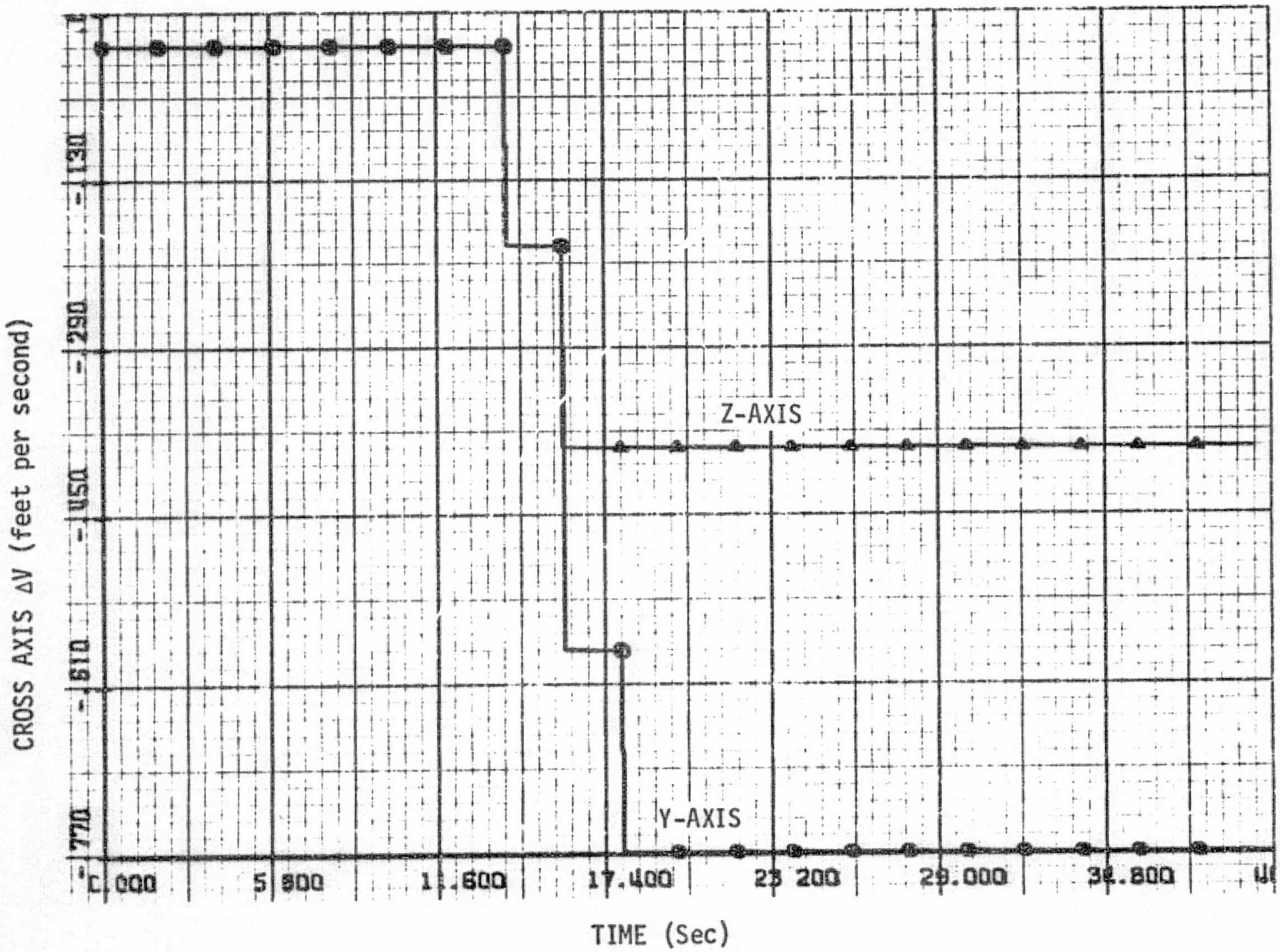

Figure 3T-7 Cross Axis ΔV Versus Time Case 3

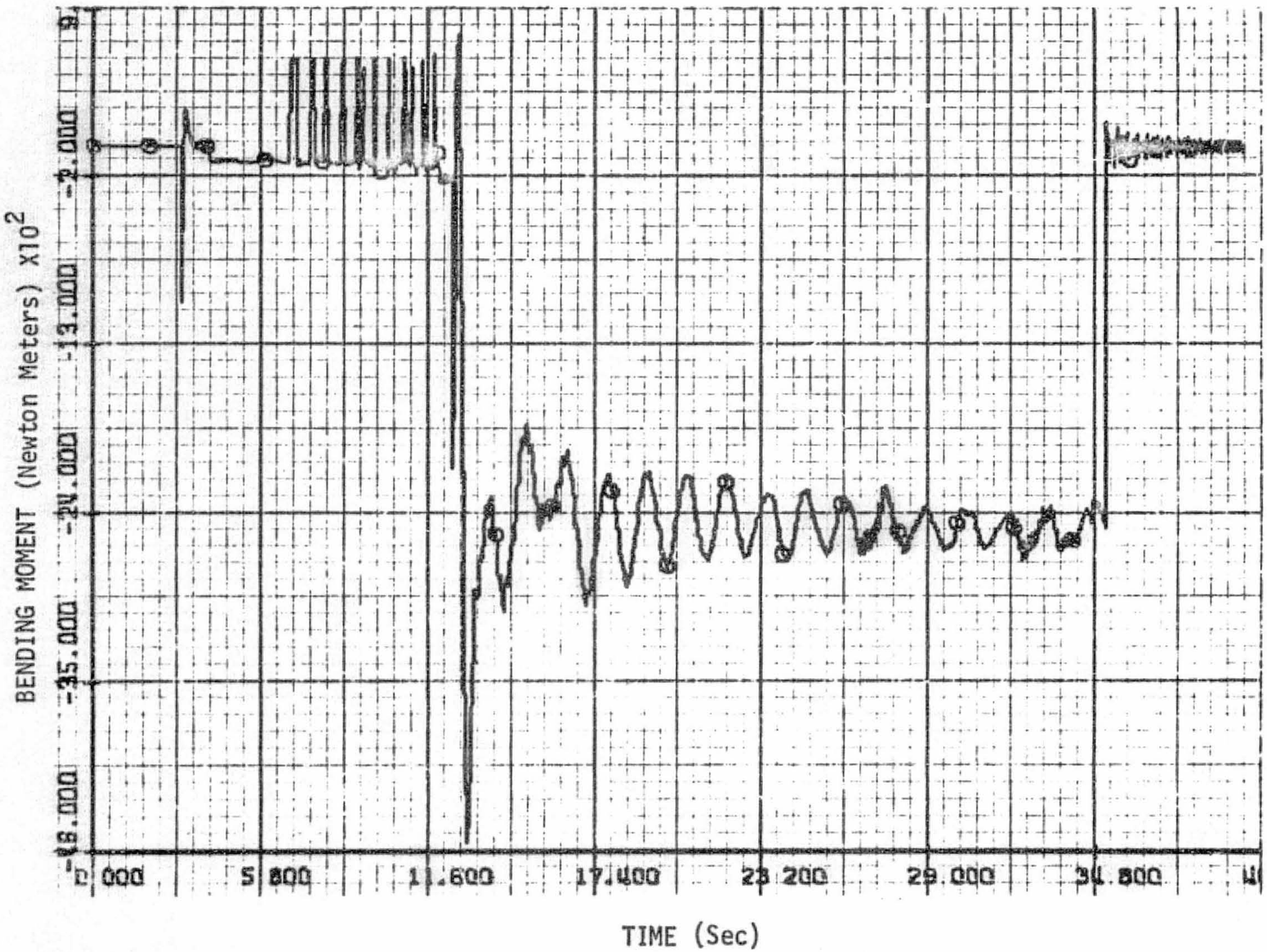

Figure 3T-8 Pitch Axis Bending Moment at Station 1010 Versus Time Case 3

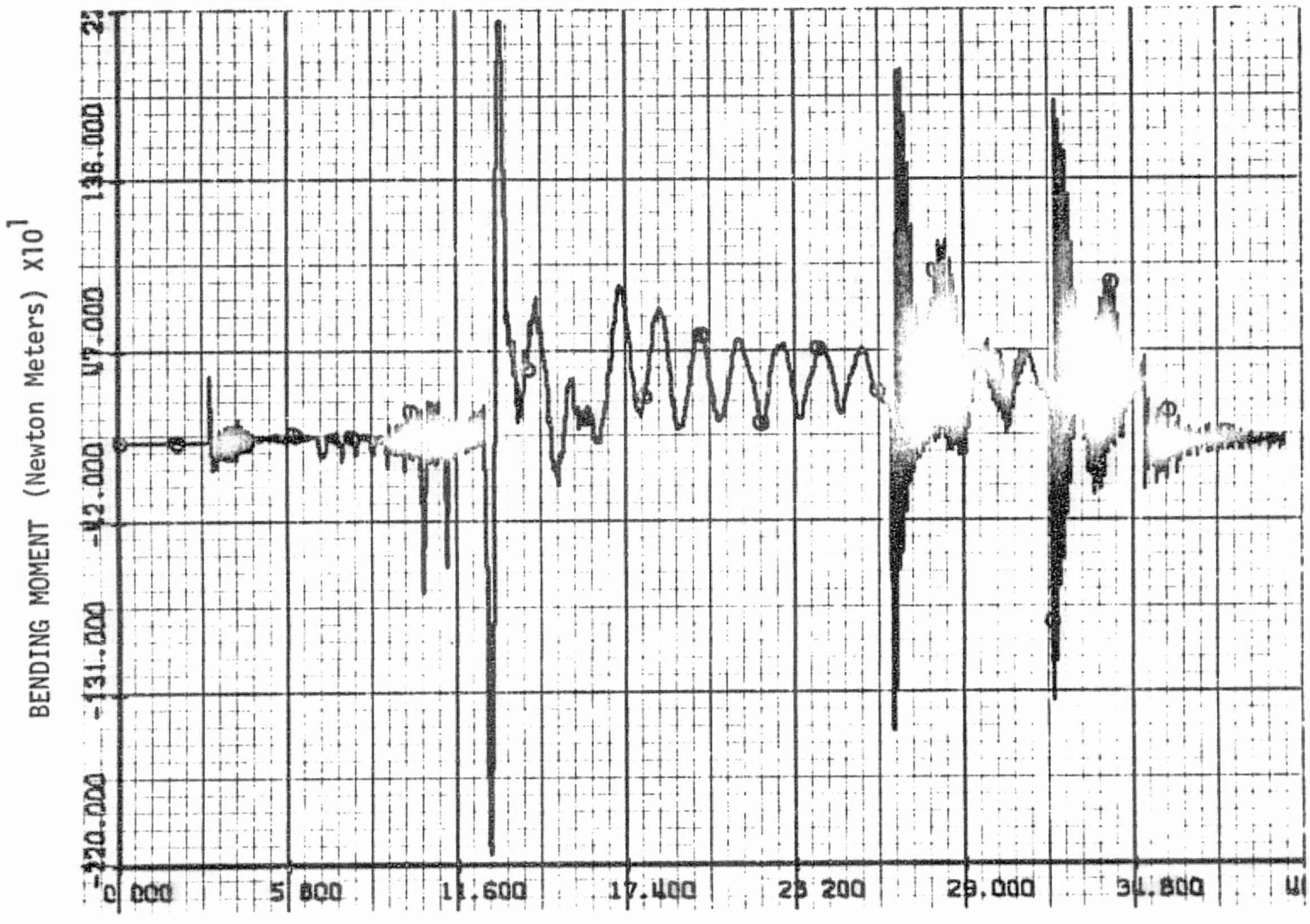

Figure 3T-9 Yaw Axis Bending Moment At Station 1010 Versus Time Case 3

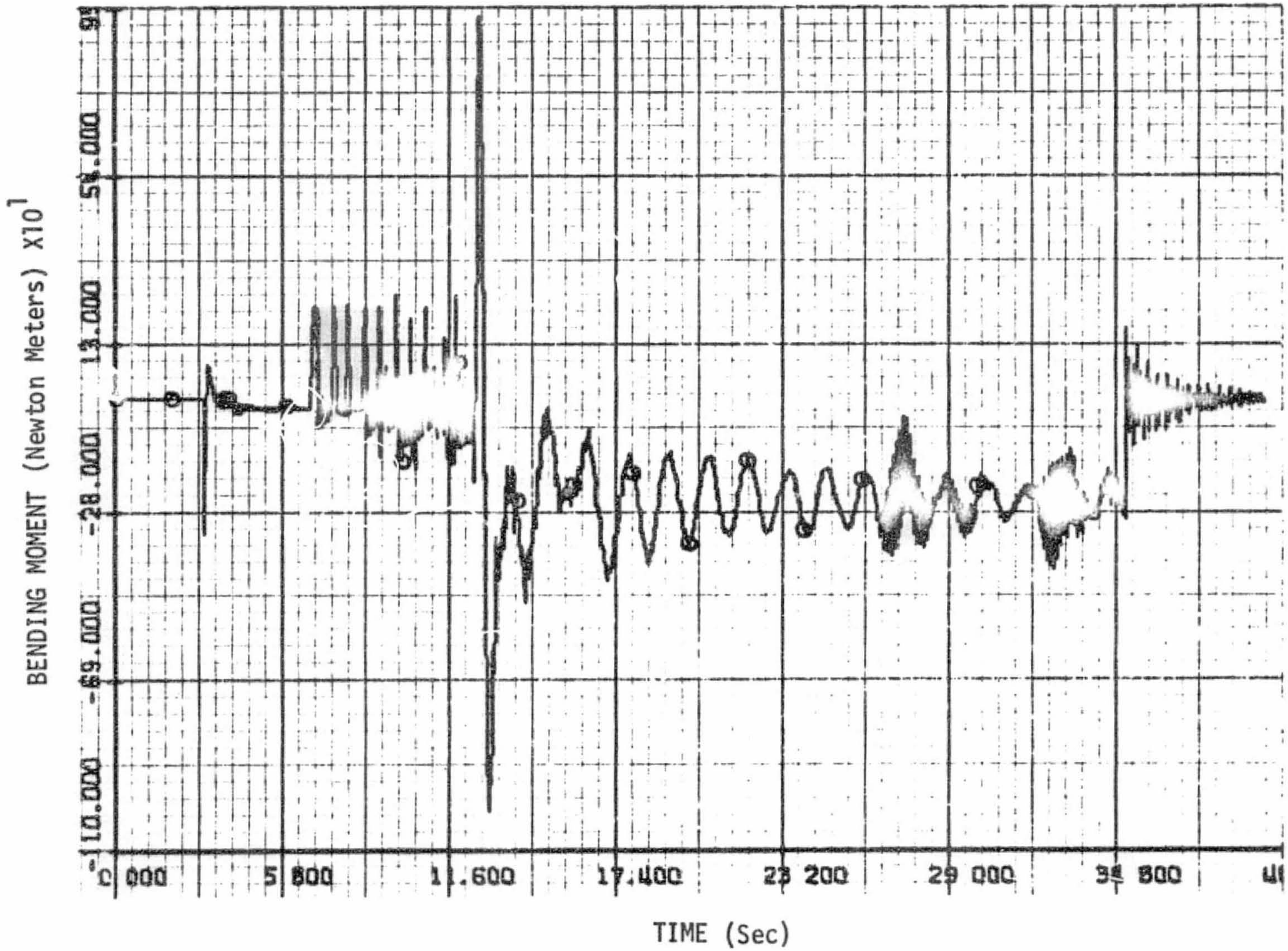

Figure 3T-10 Pitch Axis Bending Moment at Station 1109.5 Versus Time Case 3

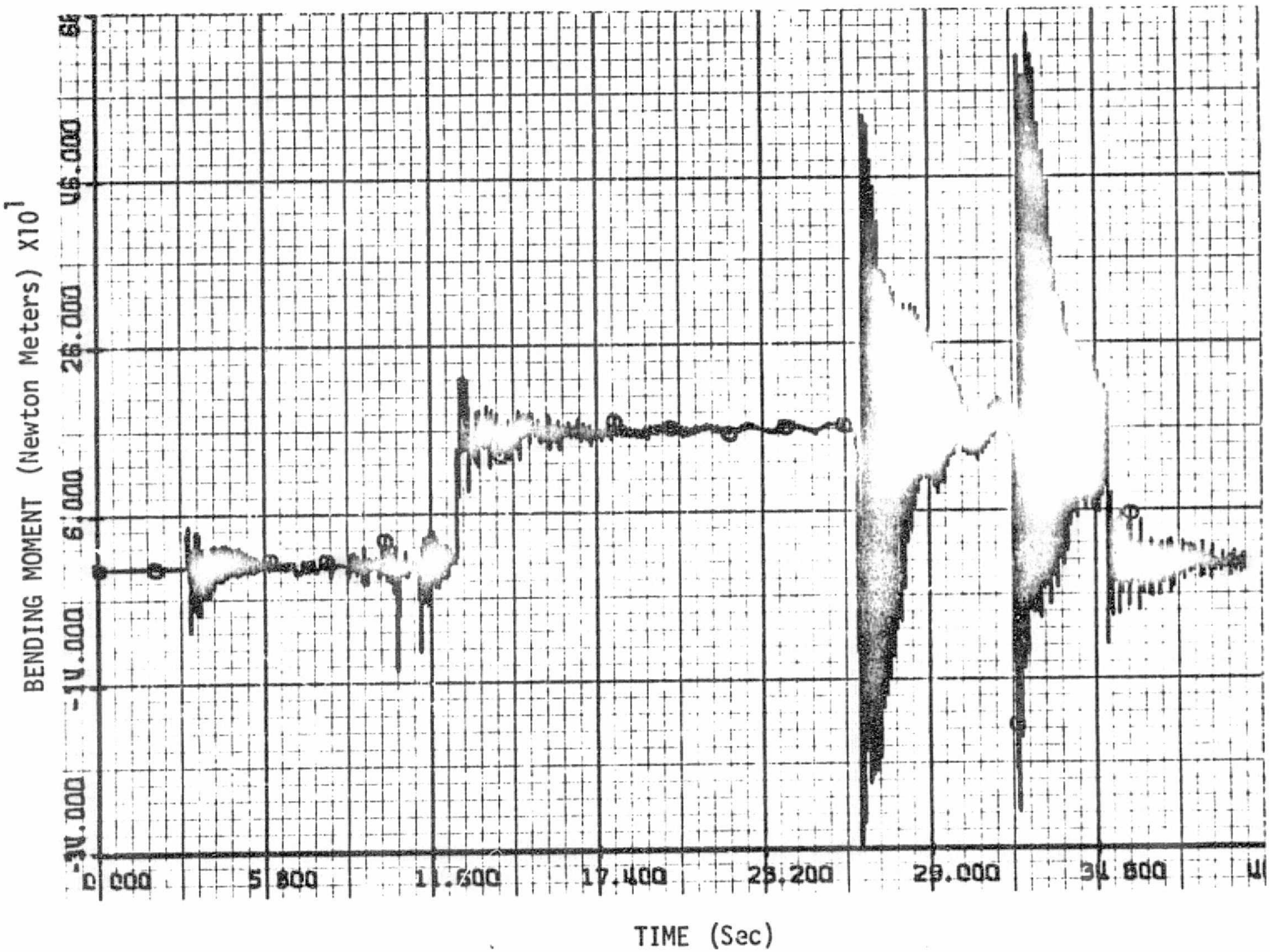

Figure 3T-11 Yaw Axis Bending Moment at Station 1109.5 Versus Time Case 3

Results for TVC Case 4

The objective of this run was to demonstrate the ability of the TVC DAP to control the CSM/DM configuration during a SPS burn. The CSM-alone DAP configuration was selected, the velocity-to-be-gained was 100 fps and the light mass properties were selected.

The TVC DAP satisfactorily controlled the CSM/DM configuration during the SPS burn. The total burn duration was 12.69 seconds. A summary of peak values of some of the major variables for this case is contained in Table 4T-1. Time histories of pertinent variables are presented in Figures 4T-1 through 4T-8.

The timeline of major events for this case is as follows:

Event	Simulation Time (sec)
SPS actuator signals enabled	3.07
Ullage on	4.07
SPS engine on	12.00
Ullage off	14.01
SPS off	23.69
Actuator signals off	26.20

The initialization for this case was identical to that of Case 2 except the light mass properties were used in this case. The light mass properties correspond to the propellant loading that will exist just prior to the time of docking with the Soyuz. Test Cases 2 and 4 used the same values for the initial SPS gimbal angles. It turned out that these gimbal angles were correct for Case 4 and were slightly in error for Case 2. As a result the transients induced at the SPS ignition were less for this case. This effect can be observed in the plots of the engine gimbal angles in Figure 4T-2 and the pitch and yaw attitude errors shown in Figure 4T-3. Another effect of the better initial SPS alignment was to reduce the cross-axis velocities. A review of the environment printout associated with this case showed that the cross-axis velocities were reduced by a factor of 2.5 for the Y axis and 5 for the Z axis. The plots of ΔV were zero for this case because the magnitudes of the cross-axis velocities did not exceed the threshold of the simulated accelerometers.

The effects of propellant slosh were slightly more noticeable in this case than in Case 2. This effect was very minute and in fact would probably not exist on the real mission. The propellant level at this point in the mission is just slightly above the screens at the lower ends of the SPS sump tanks. These screens should effectively damp any slosh at this time. The slosh model which is programmed in the SLFS represents the worst case conditions by omitting the damping effects of the screens.

The induced bending loads at the two interfaces were almost the same for the two cases. As before, the peak values of the loads were not excessive and no instability problems were observed.

Table 4T-1 Summary of Results
TVC Case 4

Maximum TVC Engine Angular Deflection

Pitch	1.9 Deg
Yaw	-1.1 Deg

Maximum Attitude Errors

Pitch	.54 Deg
Yaw	-.36 Deg

Maximum Generalized Bending Deflections

Mode 1	-.15E-3	Meters
Mode 2	.194E-4	Meters
Mode 3	-.0341E-3	Meters
Mode 4	-.058E-3	Meters
Mode 5	-.27E-4	Meters
Mode 6	-.25E-4	Meters

Maximum Slosh Displacement

Oxydizer	Y	-.02325	Meters
	Z	-.042	Meters
Fuel	Y	-.02325	Meters
	Z	-.042	Meters

Maximum Axial Load

Station 1010	385.6E2	Newtons
Station 1109.5	154.6E2	Newtons

Maximum Bending Moment at Station 1010

Pitch	-47.E2	Newton Meters
Yaw	-250E1	Newton Meters

Maximum Bending Moment at Station 1109.5

Pitch	-94E1	Newton Meters
Yaw	-35E1	Newton Meters

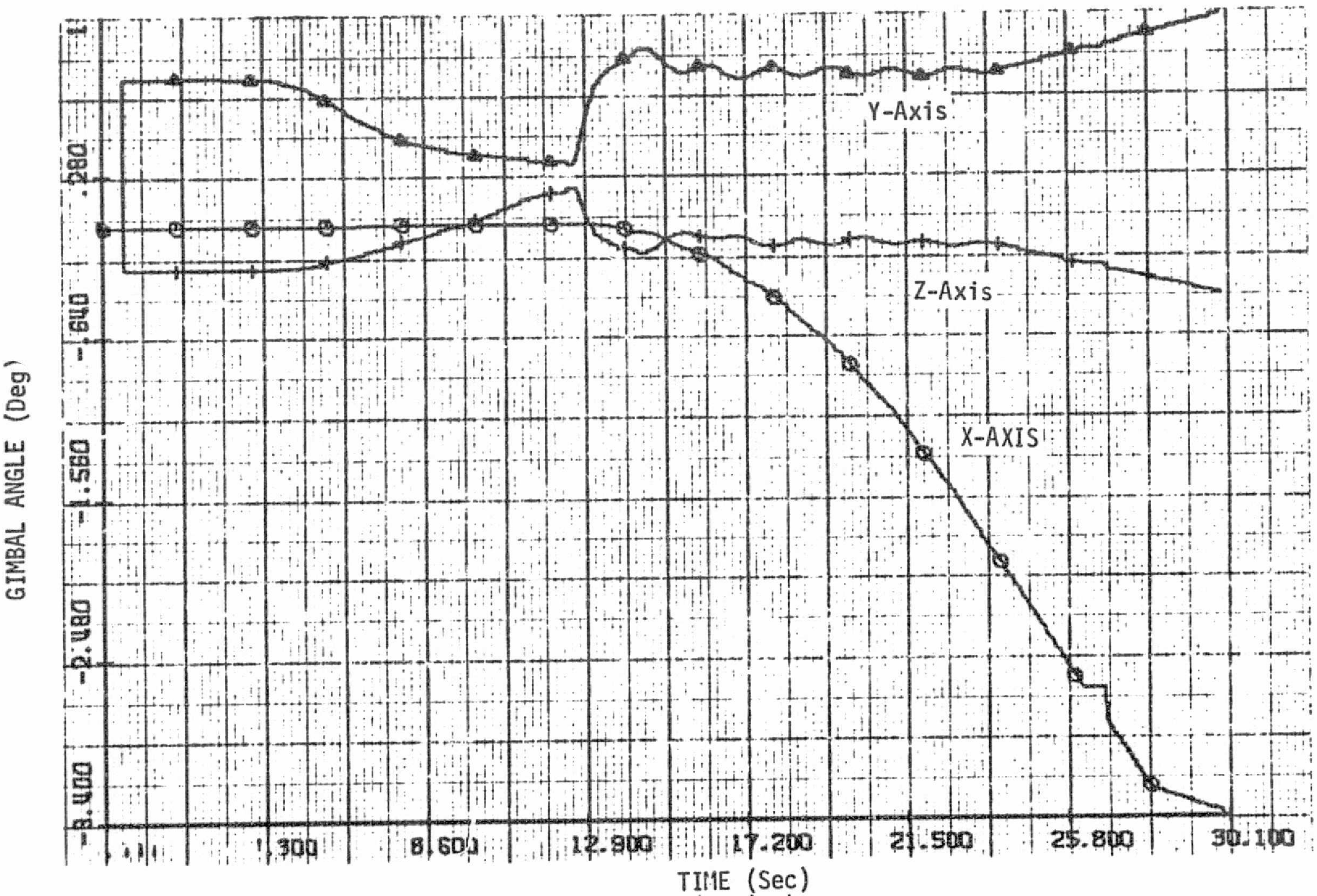

Figure 4T-1 Gimbal Angle Versus Time
Case 4

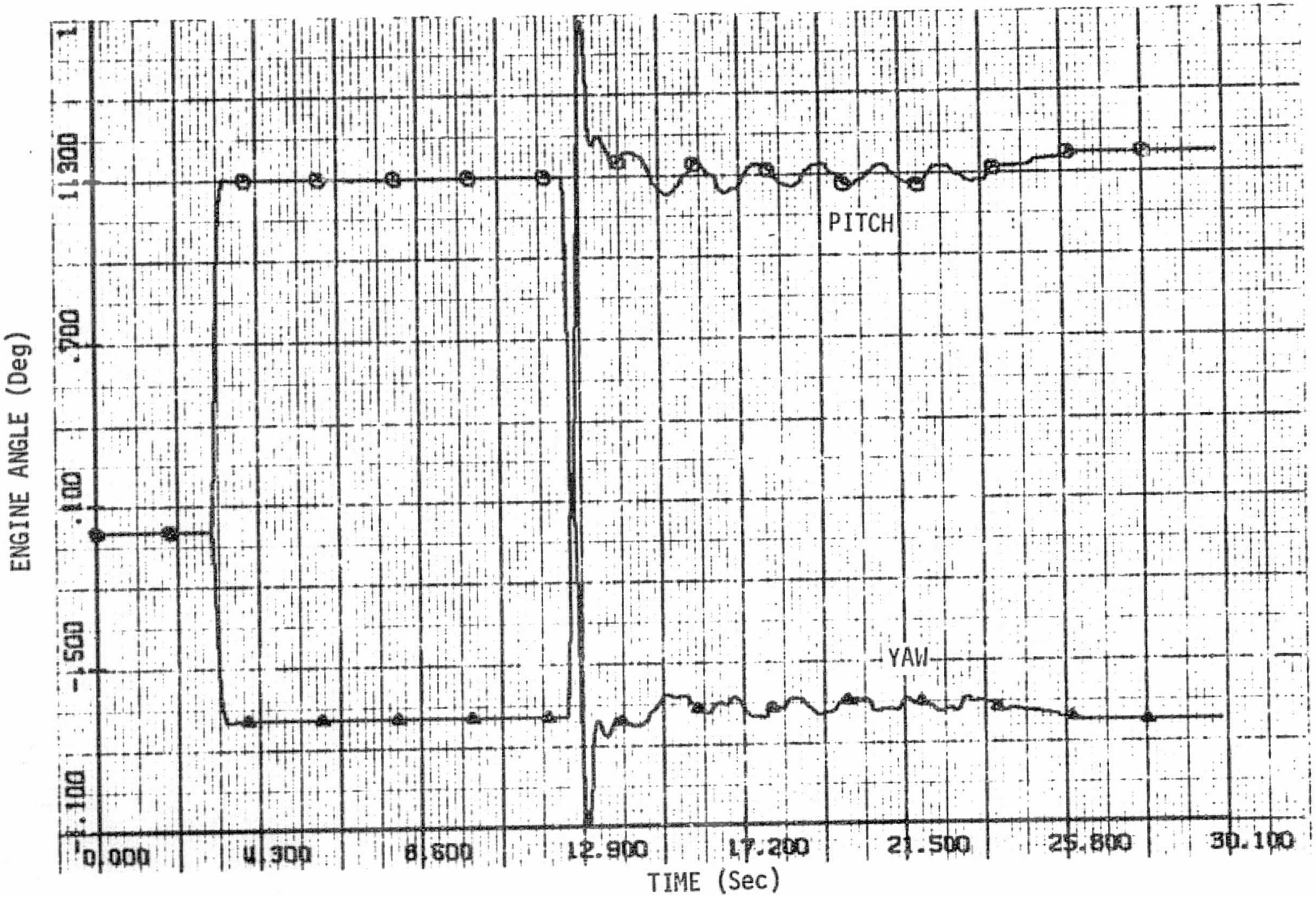

Figure 4T-2 SPS Engine Angle Versus Time
Case 4

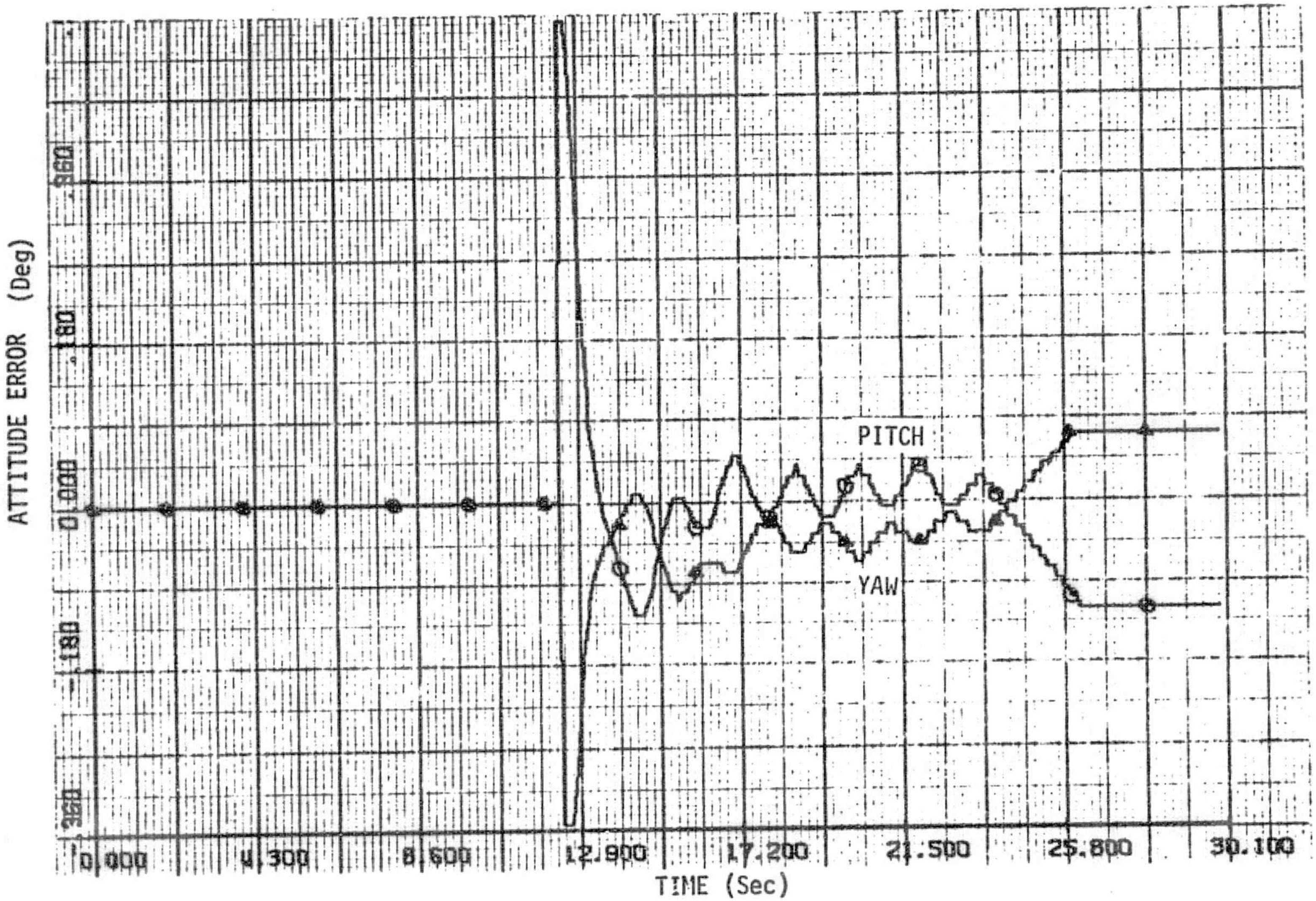

Figure 4T-3 Body Attitude Error Versus Time
Case 4

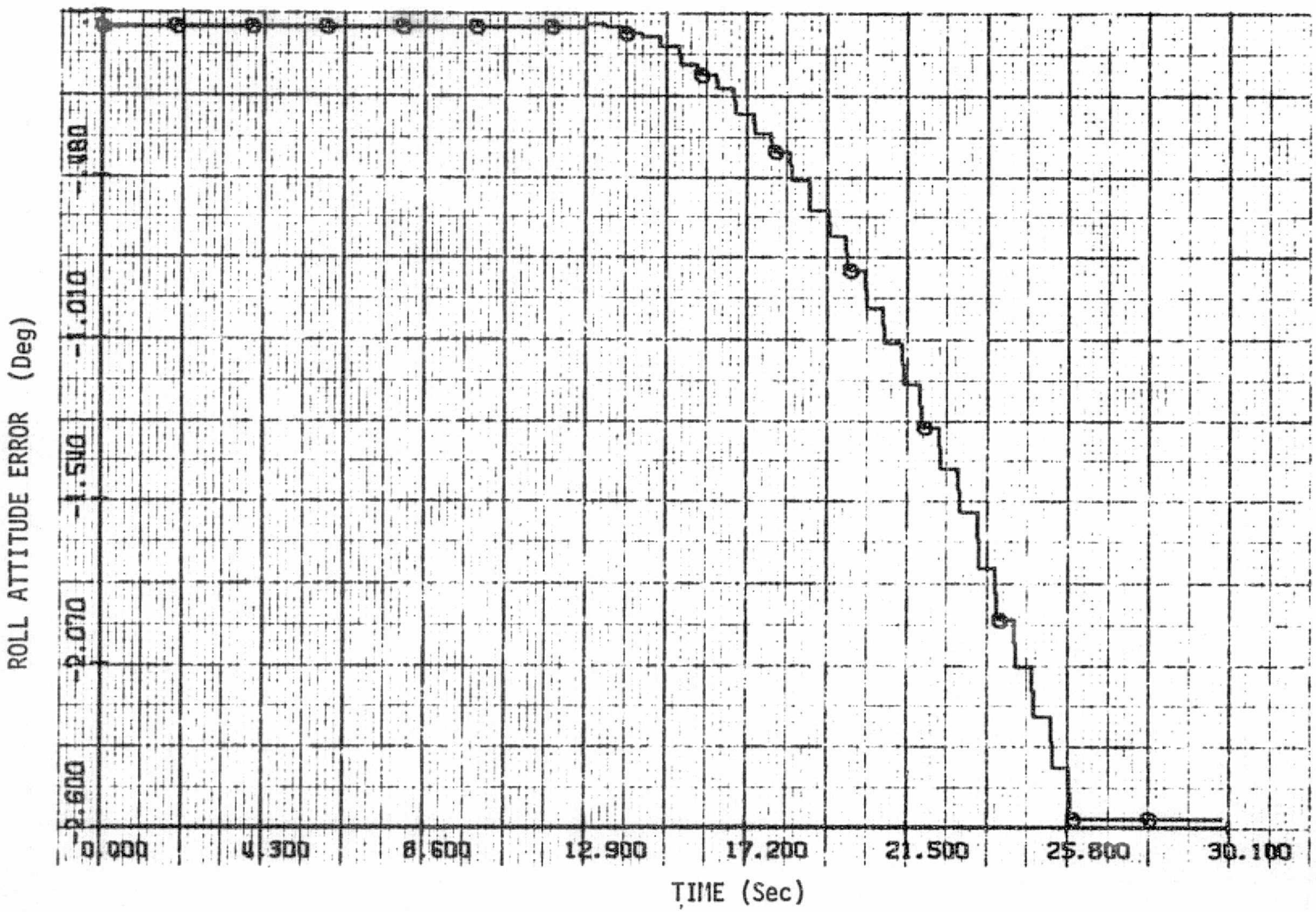

Figure 4T-4 Roll Attitude Error Versus Time Case 4

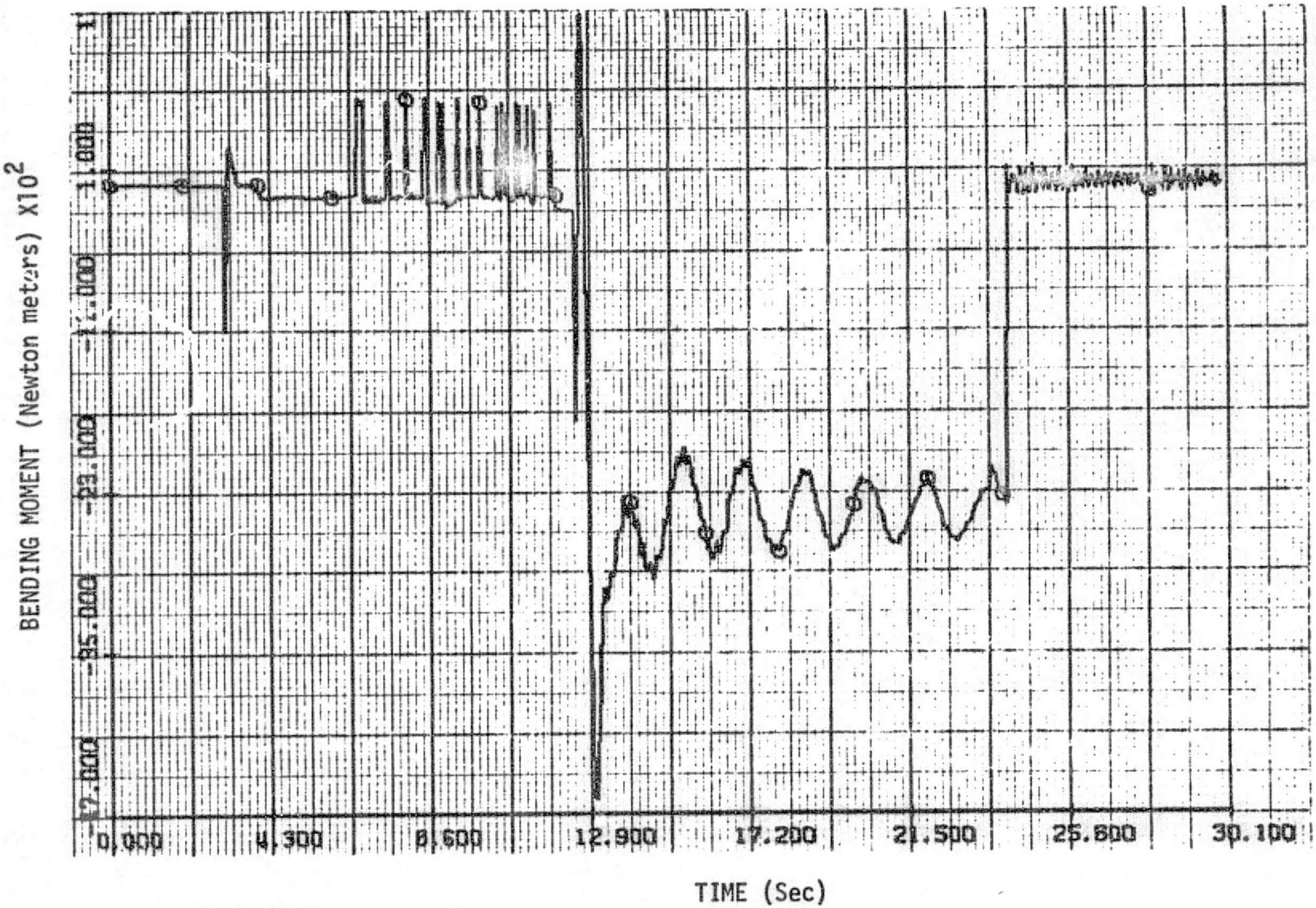

Figure 4T-5 Pitch Axis Bending Moment at Station 1010 Versus Time Case 4

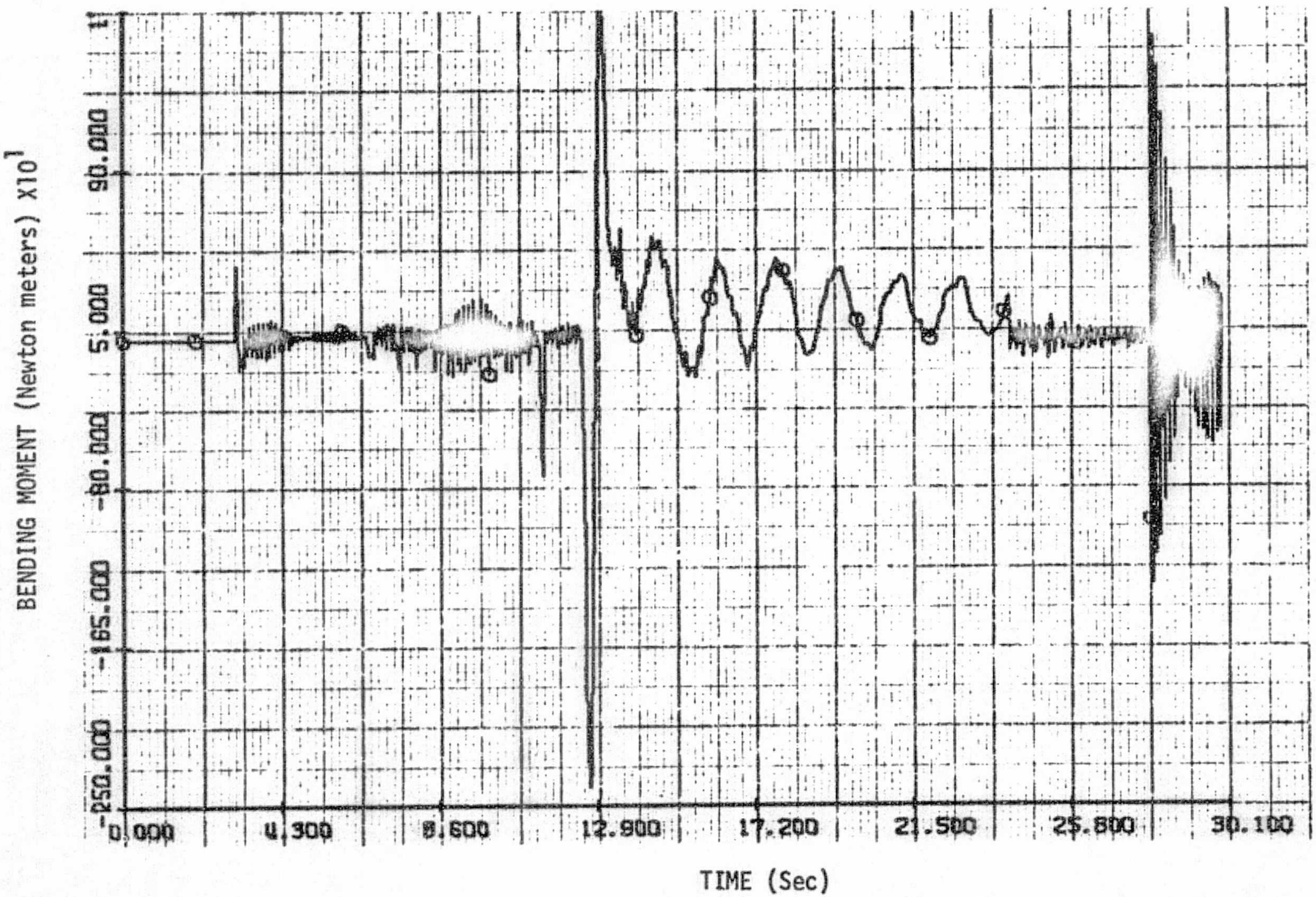

Figure 4T-6 Yaw Axis Bending Moment at Station 1010 Versus Time Case 4

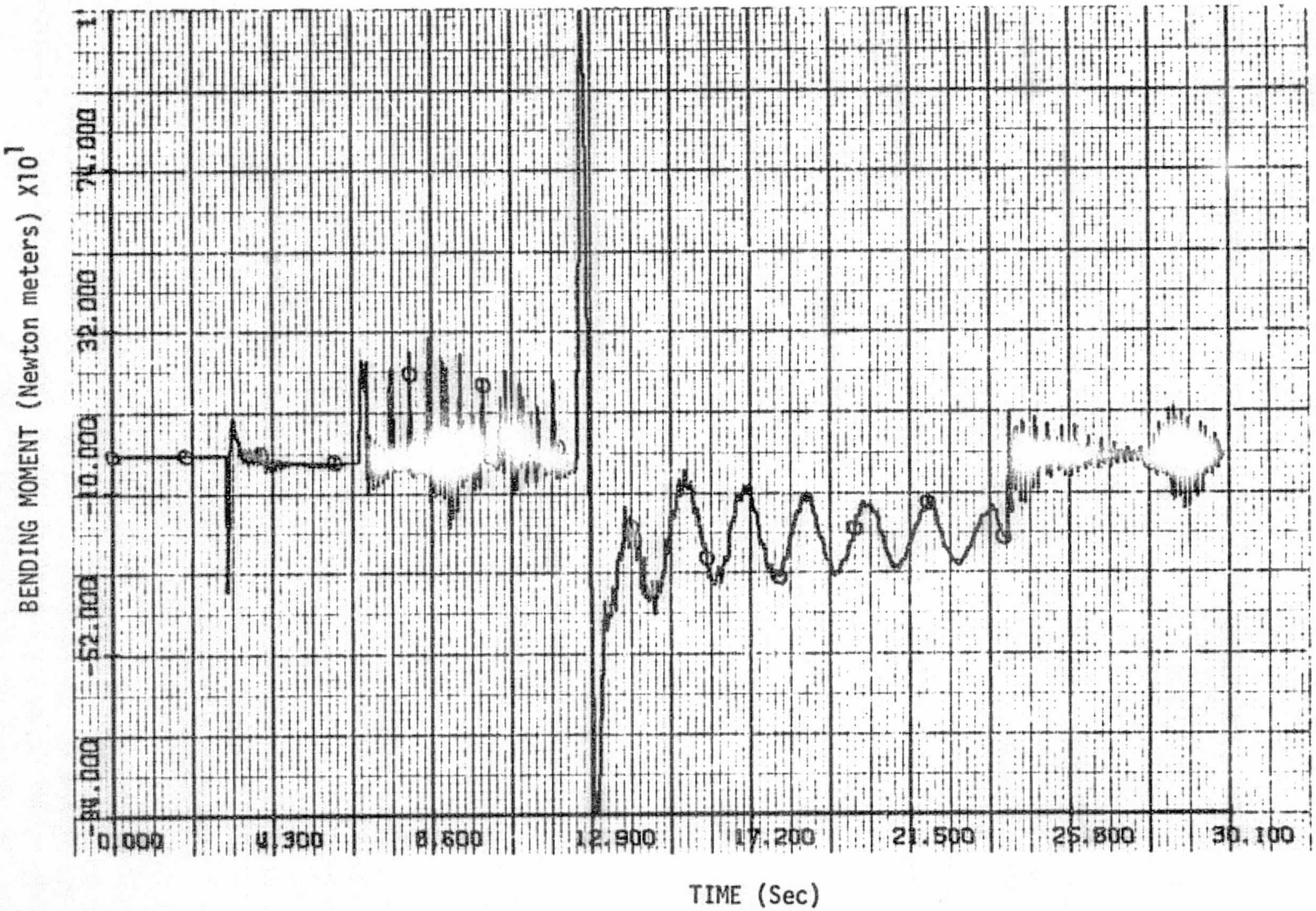

Figure 4T-7 Pitch Axis Bending Moment at Station 1109.5 Versus Time Case 4

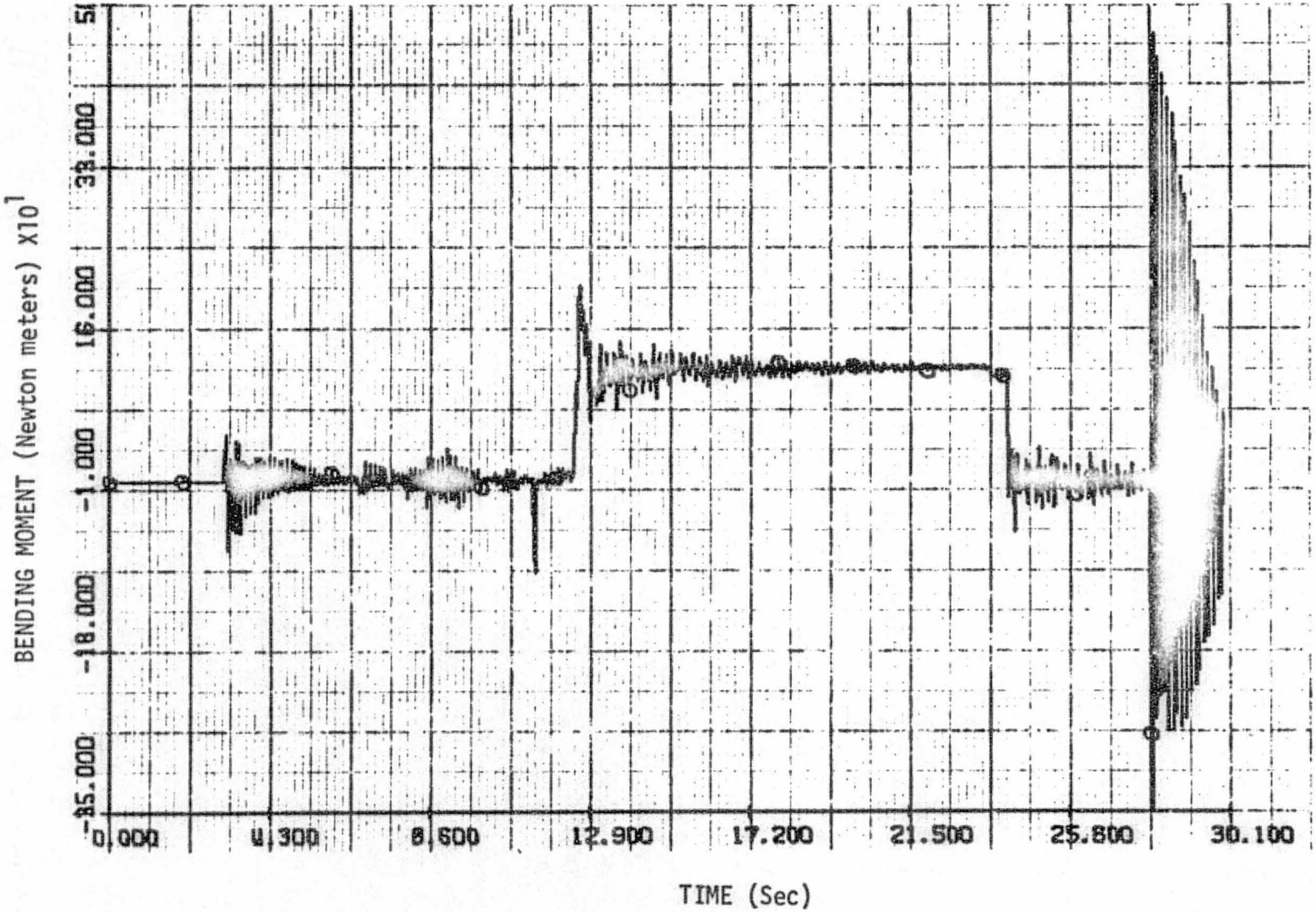

Figure 4T-8 Yaw Axis Bending Moment at Station 1109.5 Versus Time Case 4

Results for TVC Case 5

The objective of this run was to demonstrate the ability of the TVC DAP to control the CSM/DM configuration during a SPS burn. The CSM-alone DAP configuration was selected, the velocity-to-be-gained was 500 fps and the light mass properties were selected.

The TVC DAP satisfactorily controlled the CSM/DM configuration during the SPS burn. The total burn duration was 20.78 seconds. A summary of peak values of some of the major variables for this case is contained in Table 5T-1. Time histories of pertinent variables are presented in Figures 5T-1 through 5T-8.

The timeline of major events for this case is as follows:

Event	Simulation Time (sec)
SPS actuator signals enabled	3.07
Ullage on	4.07
SPS engine on	12.00
Ullage off	14.01
SPS off	32.78
Actuator signals off	35.29

The results of this case were very similar to those of Case 4. The transients induced during the SPS startup were similar to Case 4 because of the good initial alignment of the SPS gimbals. The cross-axis velocities remained small for the duration of the burn and as a result of this no guidance steering commands were issued. The effects of slosh were perceptible during the first portion of the burn but were negligible for the latter half. The induced bending moments for this case were essentially the same as Cases 3 and 4. The overall stability of the control system was good and no problems were observed.

Table 5T-1 Summary of Results
TVC Case 5

Maximum TVC Engine Angular Deflection			
Pitch		1.9 Deg	
Yaw		-1.1 Deg	
Maximum Attitude Errors			
Pitch		.5325 Deg	
Yaw		-.37 Deg	
Maximum Generalized Bending Deflections			
Mode 1		-.15E-3	Meters
Mode 2		.195E-4	Meters
Mode 3		-.033E-3	Meters
Mode 4		-.0581E-3	Meters
Mode 5		-.29E-4	Meters
Mode 6		-.25E-4	Meters
Maximum Slosh Displacement			
Oxydizer	Y	-.0168	Meters
	Z	-.03	Meters
Fuel	Y	-.0168	Meters
	Z	-.03	Meters
Maximum Axial Load			
Station 1010		358.6E2	Newtons
Station 1109.5		154.56E2	Newtons
Maximum Bending Moment at Station 1010			
Pitch		-49E2	Newton Meters
Yaw		-240E1	Newton Meters
Maximum Bending Moment at Station 1109.5			
Pitch		-110.8E1	Newton Meters
Yaw		51E1	Newton Meters

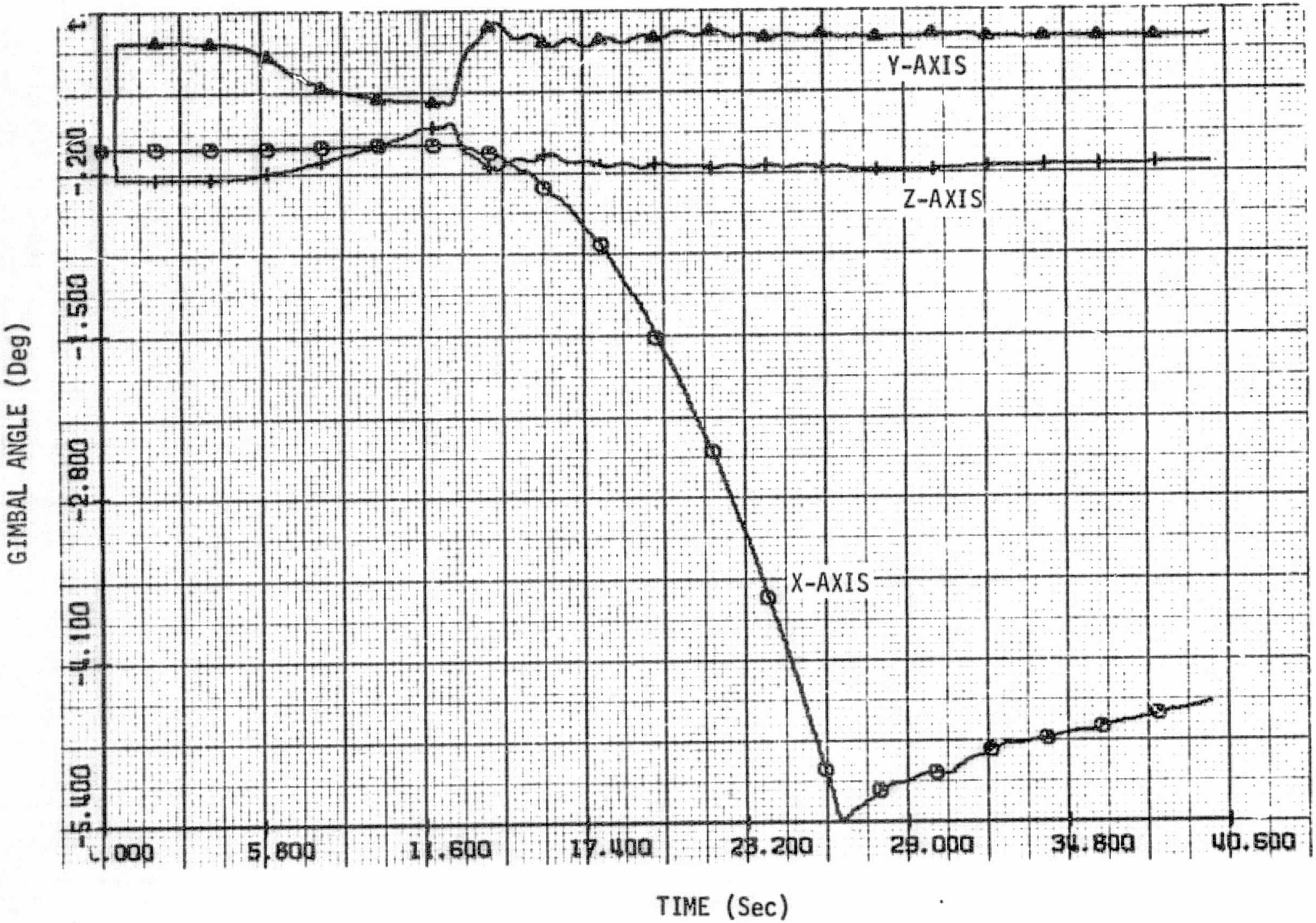

Figure 5T-1 Gimbal Angles Versus Time Case 5

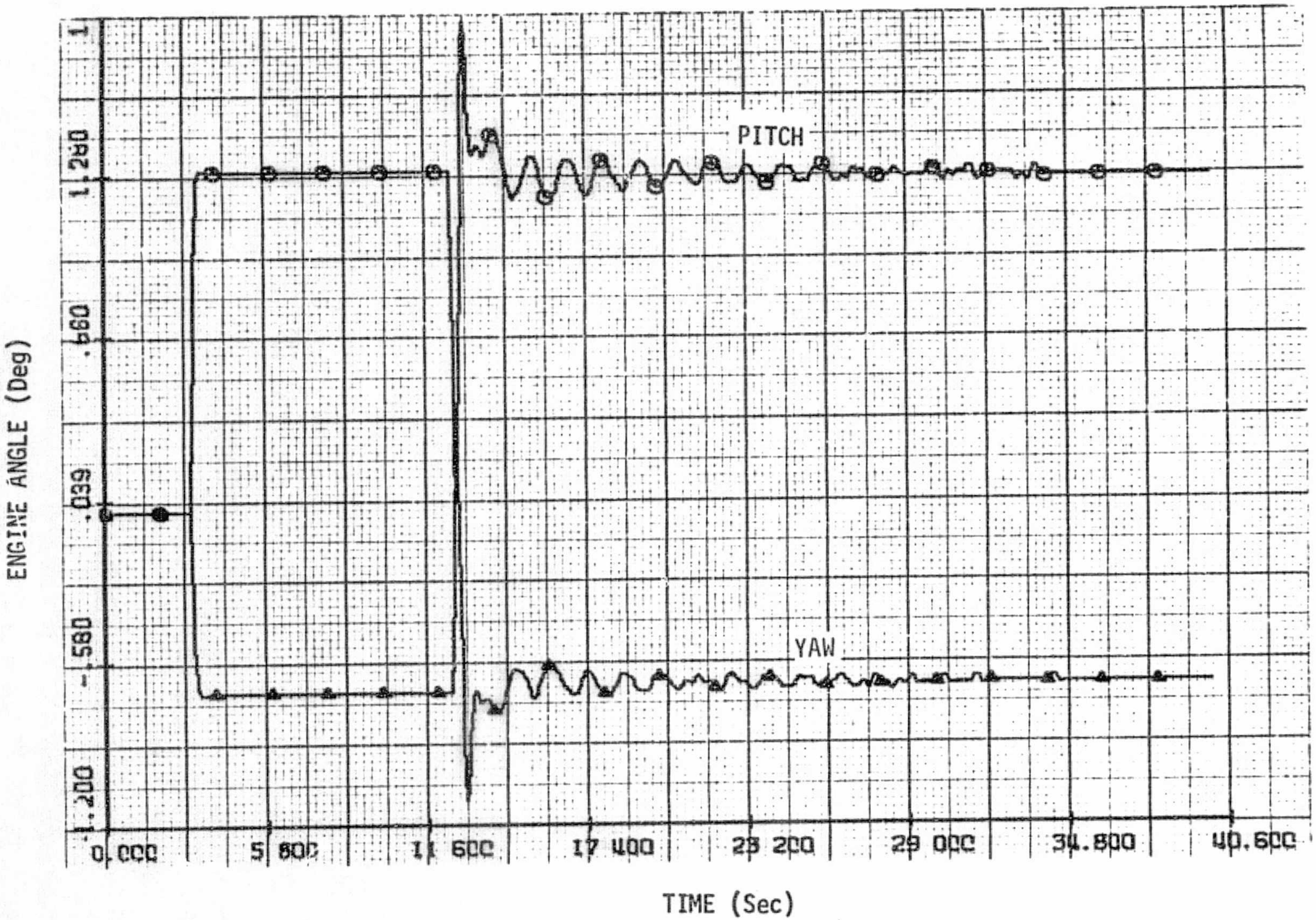

Figure 5T-2 SPS Engine Angle Versus Time Case 5

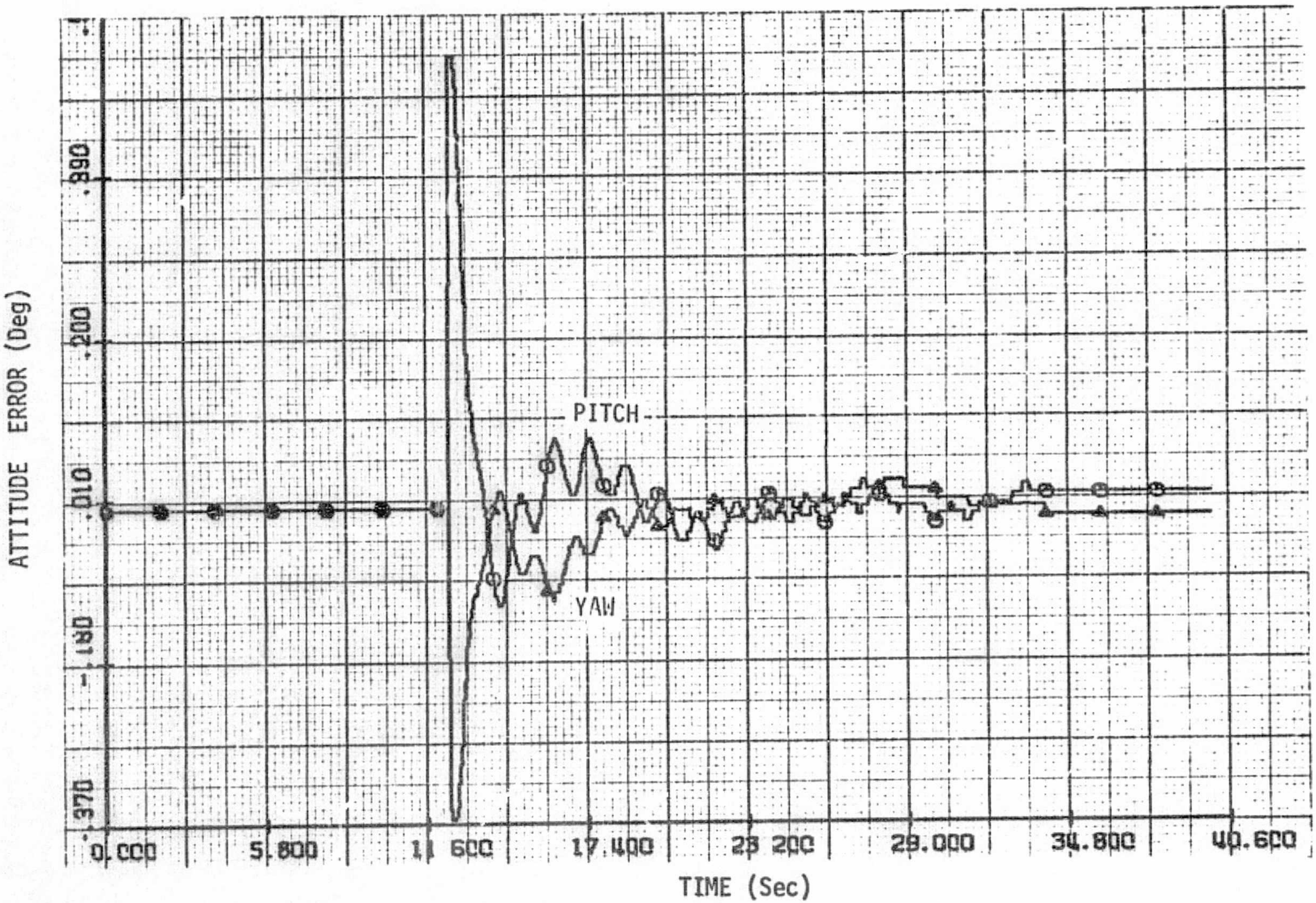

Figure 5T-3 Body Attitude Errors Versus Time Case 5

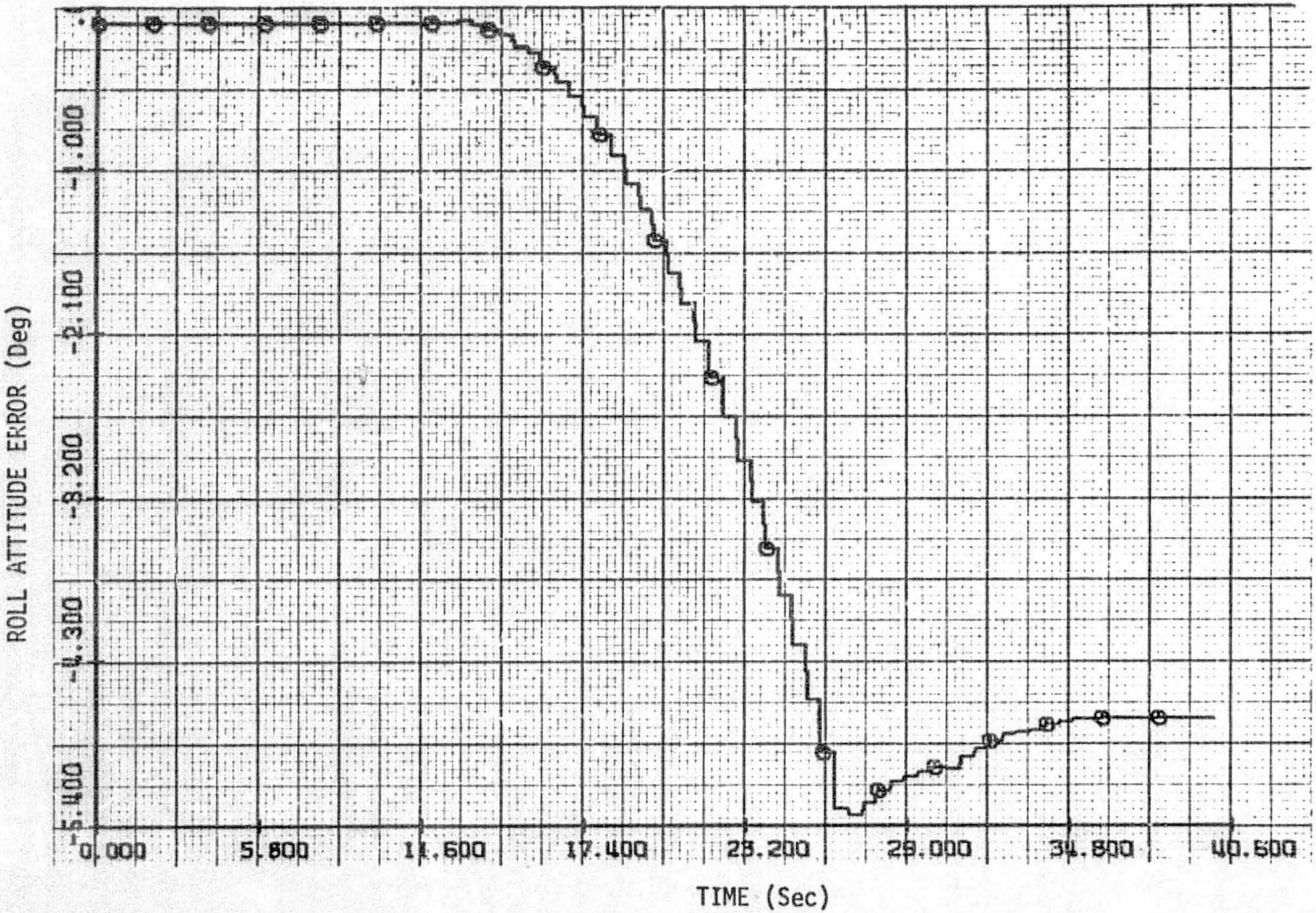

Figure 5T-4 Roll Attitude Error Versus Time Case 5

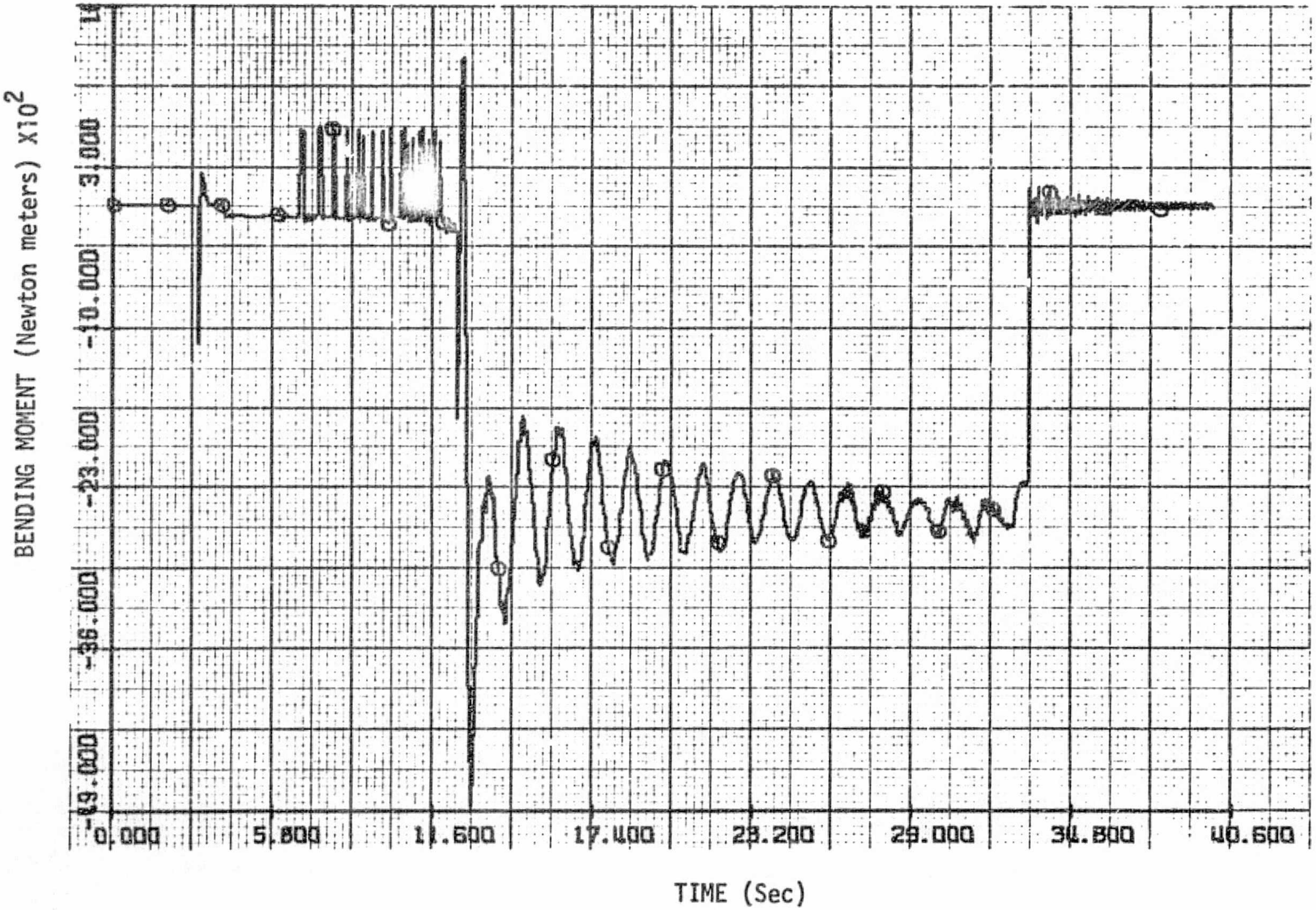

Figure 5T-5 Pitch Axis Bending Moment at Station 1010 Versus Time Case 5

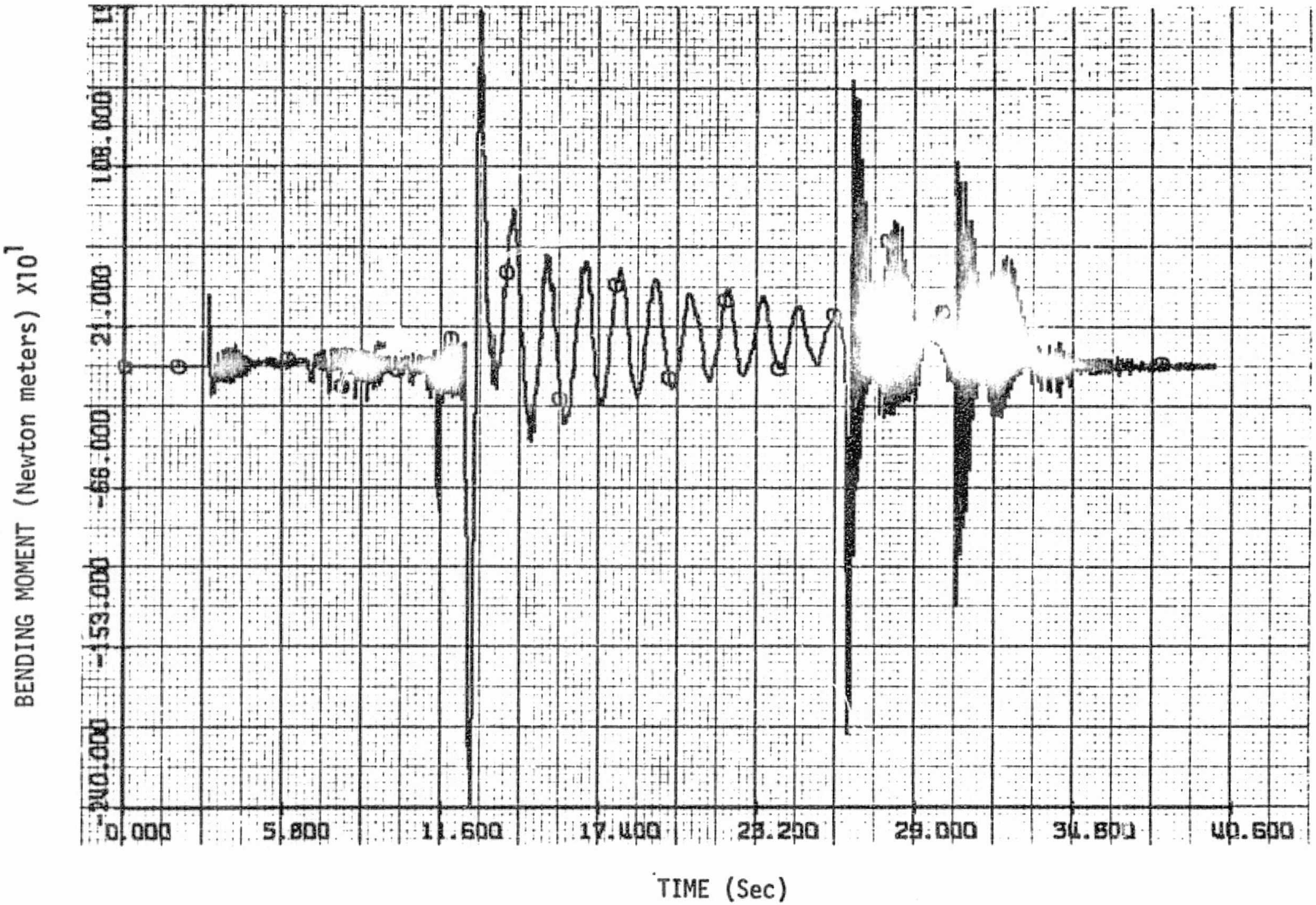

Figure 5T-6 Yaw Axis Bending Moment at Station 1010 Versus Time Case 5

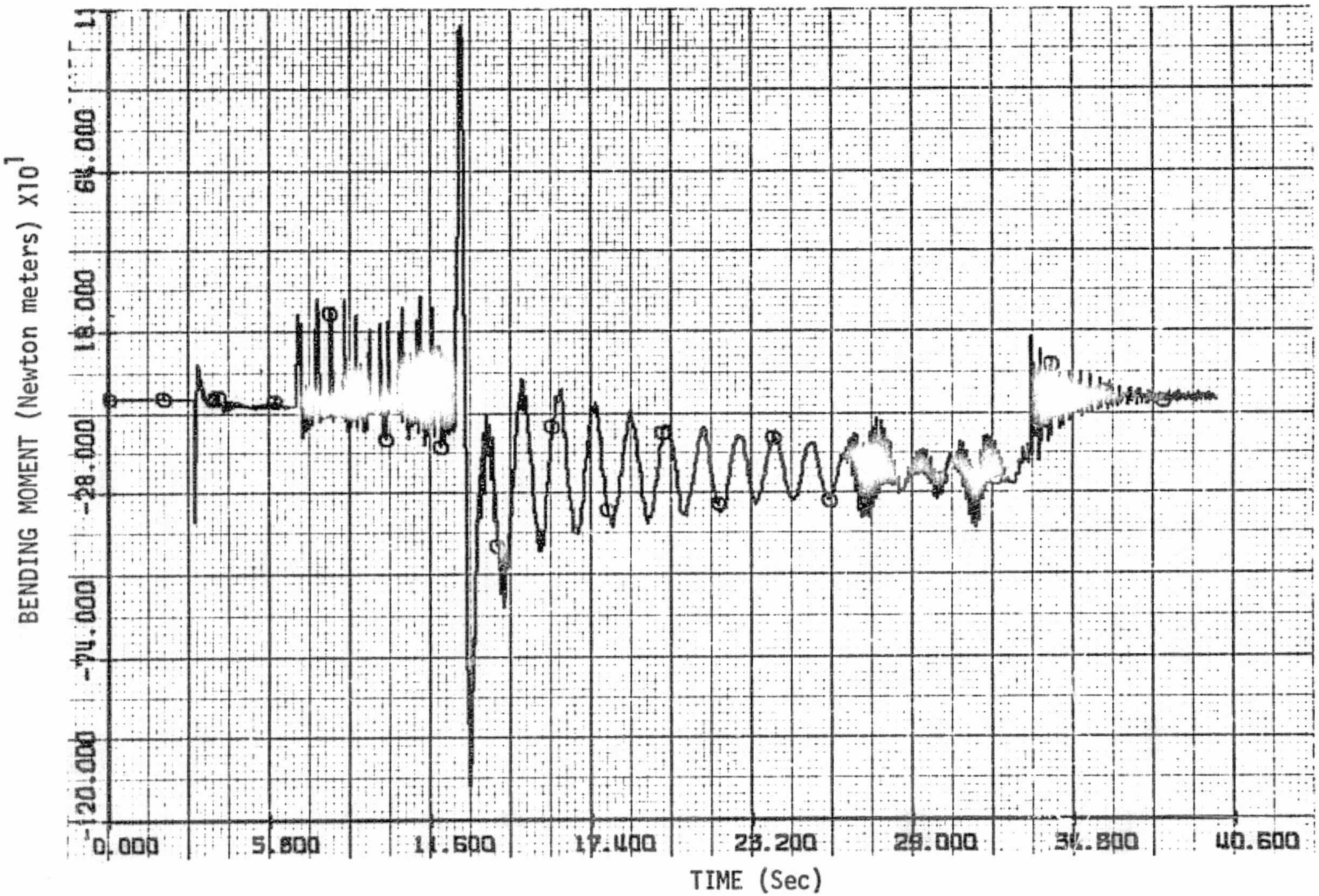

Figure 5T-7 Pitch Axis Bending Moment at Station 1109.5 Versus Time Case 5

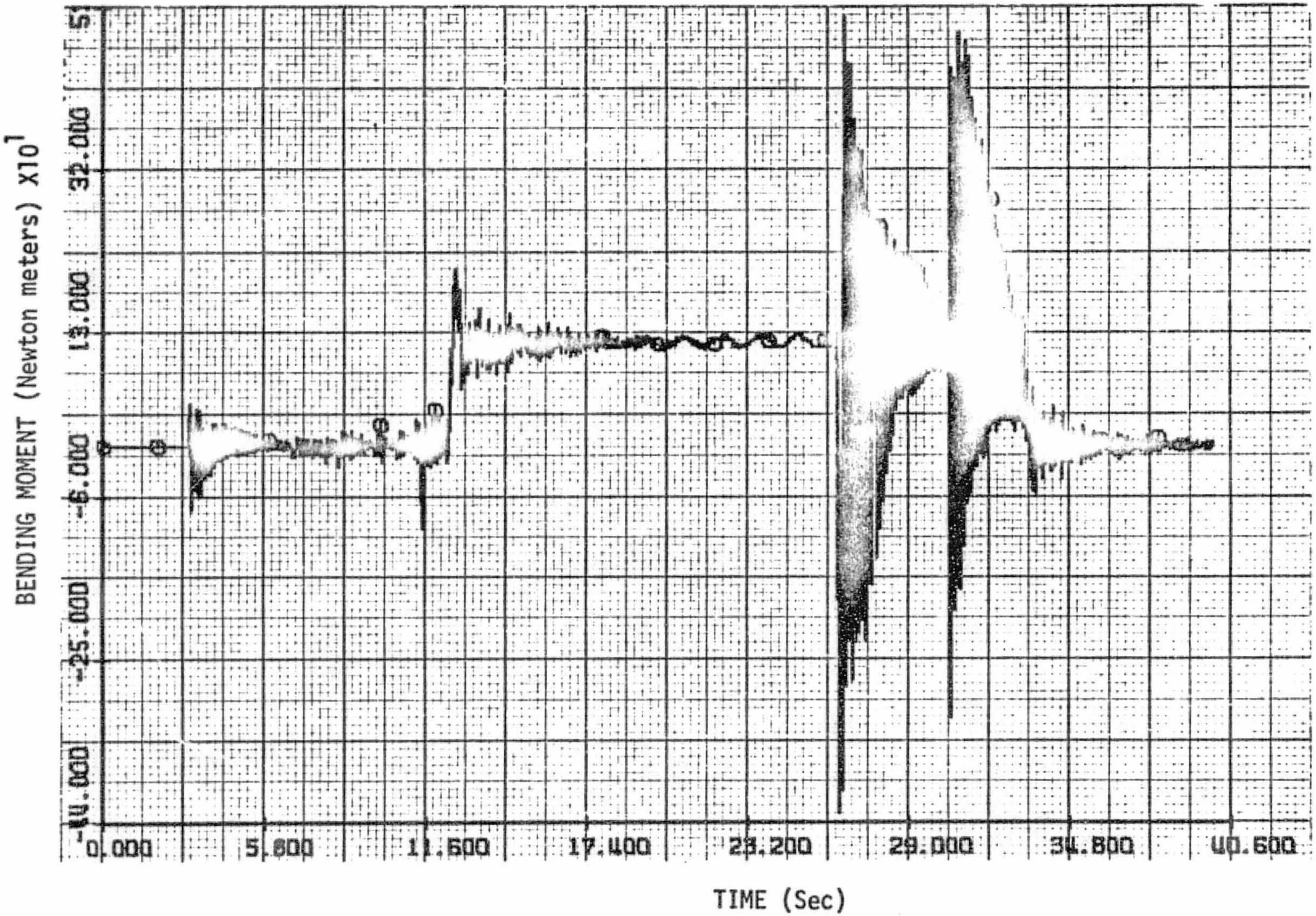

Figure 5T-8 Yaw Axis Bending Moment at Station 1109.5 Versus Time Case 5

5. CONCLUSIONS

The conclusion of this report is that the CSM RCS DAP and the CSM TVC DAP performed satisfactorily during the control of the CSM/DM configuration. The ability of the RCS DAP to perform an arbitrary three-axis automatic maneuver, provide +X axis translation, perform manual rotations and maintain an inertial attitude hold was demonstrated. It was also demonstrated that the CSM TVC DAP was able to control the CSM/DM configuration for a range of ΔV's and propellant loadings without causing a bending instability or inducing excessive loads.

Two configurations of the RCS DAP were verified. In RCS test Cases 1 and 2, the configuration digit of the DAP Data Word 1 was set to the CSM-alone configuration. This digit was set to the CSM-LM ascent configuration in RCS Test Cases 3 and 4. Both configurations performed satisfactorily. The attitude and rate time histories indicated a correct control response with minimum error excursions and adequate damping. The induced loads were essentially the same for both configurations and were within allowable limits. The only noticeable difference between the two configurations was that the CSM-LM ascent configuration required fewer individual RCS jet firings. The firings that did occur however, were longer than the comparable firings for the CSM-alone configuration and as a consequence the overall propellant consumption was essentially the same for both configurations. Thus, both configurations are capable of providing satisfactory performance and the decision as to which configuration is to be used will probably be based on operational considerations.

REFERENCES

1. Task Order JSC/TRW ASTP-E101B, "Control System Analysis," 5 December 1973.

2. MIT Charles Stark Draper Laboratory R-693, "Guidance System Operations Plan for Manned CM Earth Orbital Missions using Program Skylark 1, Section 3 Erasable Memory Program," March 1973.

3. TRW IOC 73:7153.5-123, "Test Plan for CSM/DM for ASTP," 27 July 1973.

4. TRW Technical Report 20029-H187-R0-01, "Phase 1 Verification Test Results of Apollo Stabilization and Control System During Docked Operation Revision 1," 19 October 1973.

5. TRW IOC 73:7153.7-3, "Math Models used in ASTP Testing," 8 October 1973.

6. JSC/ASED Skylab Functional Simulator (SLFS) user report (unpublished).

7. TRW IOC 73:7153.7-31, "ASTP TVC Stability Analysis for the CSM/DM Configuration using the CSM DAP," 9 December 1973.

8. JSC-07764, "Apollo/Soyuz Test Project Operational Data Book," updated 15 October 1973.

9. NASA Memo to EJ4/ASTP Chairman, Working Group 2, "ASTP Structural Dynamics Characteristics," 7 May 1973.

10. NASA Technical Memo No. DT-TM-60, "Standard Procedure for using Units of Mass, Weight, Force, Pressure and Acceleration," 1 March 1960.

11. TRW Technical Report 20029-H216-R0-00, "CSM TVC Stability Analysis Program TVCSTB," 22 October 1973.

12. NASA Memo ES2, "ASTP Structural Dynamics Characteristics," 7 May 1973.

13. NAR Internal Letter No. SSP/L&R-73-47, "Loads Data for the Guidance and Control Analysis of the CSM/Docking Module Configuration," 13 August 1973.

Appendix A Mass Data

Mass Properties Heavy

Total Weight/Mass

Weight	Mass
31756.4 lbf	987.0221 slugs
14404.5 Newtons	1468.350 kgm

C. G. Center of Mass

	X	Y	Z
inches (ARC)	990.79	1.13	2.65
meters (ARC)	25.166	0.028702	0.067310

Inertia Tensor (Heavy)

in units of Slug ft **2

$$\underline{J} = \begin{bmatrix} 16766.2 & 1098.8 & 1104.8 \\ & 77675.6 & 1057.6 \\ \text{sym} & & 77967.5 \end{bmatrix}$$

in units of kg - M **2

$$\underline{J} = \begin{bmatrix} 22731.9 & 1489.77 & 1497.91 \\ & 105314.0 & 1433.91 \\ \text{sym} & & 105709.7 \end{bmatrix}$$

Mass Properties (Light)

Total Weight/Mass

Weight	Mass
29129.8 lbf	905.3846 slugs
13213.1 Newtons	1347.361 kgm

C. G. Center of Mass

	X	Y	Z
inches (ARC)	1001.6	0.81	2.45
meters (ARC)	2.5669	0.020574	0.062230

Appendix A - continued

Inertia Tensor (Light)
in units of Slug ft **2

$$\underline{J} = \begin{bmatrix} 15065.7 & 700.2 & 1022.7 \\ \text{sym} & 69437.2 & 939.9 \\ & & 69307.8 \end{bmatrix}$$

in units of Kgm - M**2

$$\underline{J} = \begin{bmatrix} 20426.3 & 949.344 & 1386.6 \\ & 94144.2 & 1274.3 \\ \text{sym} & & 93602.7 \end{bmatrix}$$

Appendix B Structural Bending Data

Generalized Mass (for all modes) 14056.622 kg

Damping Ratio (for all modes) 0.5% critical

Model Displacements (inches/inch)

SPS Engine gimbal station

(ARC Sta. 838)

Mode	X	Y	Z
1	-1.588408E-02	6.010887E-02	1.065466E-01
2	2.861396E-03	-8,177209E-02	8.849271E-03
3	-4.131373E-03	4.254850E-01	2.475052E-01
4	5,380031E-03	-1.500827E-01	-6,659611E-01
5	-3,999534E-04	5.382679E-01	-3,700395E-01
6	1.414884E-03	-8.477696E-01	3.828574E-03

IU (Inertial Measurement Unit)

(ARC Sta. 1056)

Mode	X	Y	Z
1	9.499851E-04	-1.455643E-02	-1.382880E-02
2	3.573276E-02	-1.343814E-02	3.925697E-02
3	-1.020858E-01	-1.174196E+00	-2,423579E-01
4	2.081097E-01	-5,145670E-01	6.680671E-01
5	1.067939E-01	5.617704E-02	3.714758E-01
6	5.540934E-03	1.707381E-01	-4.209466E-03

SPS Bay 2

(ARC Sta. 838.)

Mode		X	Y	Z
1		-2.158264E-03,	5.990186E-02,	1.094576E-01
2		-6.377421E-03,	-8.132172E-02,	2,805923E-03
3		1.692192E-01,	4.993809E-01,	-2.892756E-01
4		-8.487540E-02,	-8.385867E-02,	-1.161677E+00
5		1.617626E-01,	4.816570E-01,	5.985315E-02
6		-2.087445E-01,	-8.444616E-01,	-1.175142E-01

SPS Bay 5

(ARC Sta. 838)

Mode		X	Y	Z
1		-2.992465E-02,	6.057696E-02,	1.038431E-01
2		1.167915E-02,	-8.296365E-02,	1.509835E-02
3		-1.673256E-01,	3.523494E-01,	7.834838E-01
4		8.382446E-02,	-2.187827E-01,	-1.706432E-01
5		-1.621616E-01,	-5.965090E-01,	-7.985340E-01
6		2.072452E-01,	-8.739136E-01,	1.231391E-01

RCS Quad Stations

(ARC Sta. 958.7)

	X	Y	Z
QUADA MODE 1	-5.483150E-02,	3.139108E-02,	4.467787E-02
QUADB MODE 1	7.924400E-04,	2.608435E-02,	5.321567E-02
QUADC MODE 1	2.237692E-02,	2.198520E-02,	4.714993E-02
QUADD MODE 1	-3.347178E-02,	2.560656E-02,	4.330021E-02
QUADA MODE 2	1.076253E-02,	-6.854826E-02,	2.577503E-02
QUADB MODE 2	-1.485806E-02,	-5.489463E-02,	1.566252E-02
QUADC MODE 2	-4.484966E-03,	-4.884902E-02,	2.373878E-02
QUADD MODE 2	2.215269E-02,	-5.425560E-02,	3.611555E-02
QUADA MODE 3	-1.555824E-01,	-8.556588E-01,	6.622964E-02
QUADB MODE 3	2.401699E-01,	-1,354303E-01,	-7.934008E-01
QUADC MODE 3	1.453598E-01,	6.968346E-01,	-8.641595E-02
QUADD MODE 3	-2.495750E-01,	-9.310175E-03,	7.783895E-01
QUADA MODE 4	3.846056E-01,	-7.519320E-01,	1.160984E-01
QUADB MODE 4	-3.601191E-02,	-6.748807E-02,	-6.819407E-01
QUADC MODE 4	-3.663964E-01,	7.097135E-01,	-1.519972E-02
QUADD MODE 4	5.055549E-02,	4.782769E-02,	7.947583E-01
QUADA MODE 5	1.649034E-01,	5.796916E-01,	-4.417205E-02
QUADB MODE 5	3.141325E-01,	2.234567E-02,	6.728293E-01
QUADC MODE 5	-1.676565E-01,	-6.882834E-01,	8.579236E-02
QUADD MODE 5	-3.026772E-01,	-9.227771E-02,	-6.039209E-01
QUADA MODE 6	3.157827E-02,	-4.741464E-01,	1.765215E-02
QUADB MODE 6	-3.331369E-01,	-3.078431E-01,	-1.942861E-01
QUADC MODE 6	-2.783227E-02,	-9.338838E-02,	-1.998152E-02
QUADD MODE 6	3.326411E-01,	-2.719268E-01,	1.882849E-01

Modal Slopes (Radians/inch)

SPS Engine Gimbal Station

(ARC Sta. 838)

Mode	X, Y, Z
1	0.0, 4.074471E-04,-2.326708E-04
2	0.0,-1.391615E-04, 1.430408E-04
3	0.0, 1.866724E-03,-3.531680E-03
4	0.0,-5.083840E-03, 1.058810E-03
5	0.0,-2.801541E-03.-4.064891E-03
6	0.0, 3.110833E-05, 4.345864E-03

IU (Inertial Measurement Unit)

(ARC Sta. 1056)

Mode	X, Y, Z
1	1.725040E-04, 3.475158E-04,-2.297441E-04
2	-3.364750E-04, 5.837041E-04, 8.379065E-04
3	1,552838E-02.-1.572494E-03, 4.285164E-03
4	1.508034E-02, 1.631460E-03,-1.366132E-03
5	-1.540992E-02, 4.827804E-04, 3.799859E-03
6	2.366449E-03, 2,882949E-04, 6.511739E-04

Bending Frequencies (Hz)

Mode	Frequency
1	5.6309
2	6.5244
3	7.9615
4	8.4785
5	8.5141
6	10.9992